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The Institution of Electrical Engineers.

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[*Continued on page (III) of Cover.*

H. G. Young.

PRESIDENT 1936-1937

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THE JOURNAL OF
The Institution of Electrical Engineers
VOL. 80.

INAUGURAL ADDRESS

By H. T. YOUNG, President.

(*Address delivered before* THE INSTITUTION *22nd October*, 1936.)

It is my privilege to give the first Presidential Address in the reign of King Edward VIII, who has so graciously become our Patron. For this honour, and for the acknowledgment given to the installation and contracting section of our industry by my election as your President, I am indeed grateful.

The history of The Institution, and the important position which it maintains in the affairs of the nation, make me fully conscious of the responsibilities attached to the office in which you have placed me. The great achievements of my recent as well as early predecessors may not be within my reach, but it is my ambition and intention to serve The Institution and its members to the utmost of my ability, and I thank you for electing me.

Early in the year, this country, the Dominions, and the whole civilized world, were saddened by the death of King George V. He was loved and respected throughout the world, and during his reign our Institution grew and prospered. Through our radio services, King George was enabled to speak to his people within the Empire, and to be heard by other nations near and far, bringing all who listened to a closer understanding of our democratic British monarchy. We are proud to think that the technical skill of members of this Institution has played so large a part in making possible his late Majesty's broadcasts.

It is often necessary to look back into the past in order to appreciate the present and to obtain a proper perspective of what our imagination pictures for the future. I propose, therefore, to give you a brief outline of the growth of The Institution and some sections of the electrical industry during the reign of our late King.

THE INSTITUTION, 1910–1936

It is interesting to note that the first Presidential Address to be delivered in this building (on the 10th November, 1910) was given in the first year of our late King's reign.

Table 1 shows the names of the 22 members of The Institution who occupied the Presidential chair during that period, and the sections of the electrical profession and industry which they represented. It also shows year by year the number of members and the income of The Institution. It will be seen that in the first year of his late Majesty's reign the membership was 6 343, and that, with the exception of the years affected by the Great War, there has been a steady annual growth to the figure of 16 788—the number given in the Annual Report of the Council last May.

I do not propose to analyse in detail the growth of the various classes of membership, but I would especially draw your attention to the Graduate class. It numbers to-day 3 941. The importance of this class in our membership scheme as re-constituted in 1929 was not at first fully apparent to all members, but it is now appreciated that it marks the technical qualifications of our younger members, and year by year the prestige of this class has increased.

The work of The Institution and of the Council has been regularly reviewed in the Annual Reports and in the *Journal*, and, as the membership grows and electrical science develops, the Council, the various Committees of The Institution, and its representatives on Committees associated with other societies and institutions, have ever-increasing responsibilities to carry.

The advances and developments in electrical science and engineering have been under review continually in the papers presented to The Institution and in the annual Addresses delivered by the Presidents and the Chairmen of Local Centres and Sub-Centres. Our records have, indeed, chronicled every great advance in invention, design, manufacture, and operation. The activities of The Institution are, of course, primarily the reflection of the work of its members.

During the period under review, four new Local Centres and seven Sub-Centres have been established at home, and 12 Local Committees overseas. These are all serving The Institution loyally and efficiently.

Separate sections have also been set up to deal with the more specialized activities, namely:

	Year
Wireless Section	1919
Meter and Instrument Section	1928
Transmission Section	1934

Separate committees conduct the affairs of these Sections, and the results achieved have justified the adoption of a policy of de-centralization.

The granting of the Royal Charter in 1921 was an important event in our history, and The Institution's share in the Faraday Celebrations 10 years later, in 1931, will long be remembered. The floodlighting of the Royal Palaces and many important buildings revealed to the industry the public's appreciation and pleasure aroused by this comparatively new art; and the opportunity then presented was repeated on the occasion of the Silver Jubilee, with equally gratifying results.

A matter of further interest is that to-night's meeting is the first to be held by The Institution in an all-electric building. During the summer recess the old coke-fired boilers for heating the building have been replaced by an electrode boiler. The ventilating system of this lecture theatre has been remodelled, and the air is now filtered and warmed electrically. We may hope that this, with the redecoration, will considerably brighten the atmosphere of this room.

Table 1

Session	*Name*	*Interest*	*Members*	*Income* £
1910–11	S. Z. de Ferranti	Manufacturing	6 343	11 722
1911–12	S. Z. de Ferranti	Manufacturing	6 537	12 062
1912–13	W. Duddell, F.R.S.	Consulting	7 084	15 910
1913–14	W. Duddell, F.R.S.	Consulting	7 045	18 251
1914–15	Sir John Snell, G.B.E.	Consulting	6 811	16 466
1915–16	C. P. Sparks, C.B.E.	Consulting	6 676	16 074
1916–17	C. P. Sparks, C.B.E.	Consulting	6 613	16 608
1917–18	C. H. Wordingham, C.B.E.	Admiralty	6 667	18 775
1918–19	C. H. Wordingham, C.B.E.	Consulting	7 023	21 604
1919–20	R. T. Smith	Railways	8 146	26 901
1920–1	Ll. B. Atkinson	Cables	9 449	29 773
1921–2	J. S. Highfield	Consulting	10 275	32 813
1922–3	F. Gill, O.B.E.	Telegraphs and Telephones	10 911	35 659
1923–4	A. Russell, M.A., D.Sc., F.R.S.	Education	11 415	36 255
1924–5	W. B. Woodhouse	Electricity Supply	11 743	34 162
1925–6	R. A. Chattock	Electricity Supply	12 142	35 620
1926–7	W. H. Eccles, D.Sc., F.R.S.	Consulting	12 647	37 454
1927–8	Sir Archibald Page	Electricity Supply	13 043	38 419
1928–9	Lt.-Col. K. Edgcumbe, T.D.	Measuring Instruments (Manfg.)	13 561	40 699
1929–30	Colonel Sir Thomas F. Purves, O.B.E.	Communications	14 200	42 413
1930–1	C. C. Paterson, O.B.E.	Research	14 670	45 423
1931–2	J. M. Donaldson, M.C.	Electricity Supply	14 884	46 300
1932–3	E. W. Marchant, D.Sc.	Education	15 149	46 756
1933–4	P. V. Hunter, C.B.E.	Cables	15 619	45 851
1934–5	W. M. Thornton, O.B.E., D.Sc., D.Eng.	Education	16 150	48 908
1935–6	J. M. Kennedy, O.B.E.	Electricity Commission	16 788	50 672

Here it will be appropriate to mention that, during the 25 years under review, Mr. Rowell has very capably carried the responsibility of Secretary, assisted by the competent staff he has selected.

From all the Committees that do so much work for the industry and profession, time will permit me to mention only two, which have a special relation to the electrical equipment of buildings—the main subject of this Address. The first is the committee set up to investigate and report on electrical interference with broadcasting. The Report of this Committee is a document that will make history in the annals of this Institution; it is now receiving the consideration of the Government. It brings out two characteristics of electrical engineering to-day which are well worthy of notice. First: that the older and more developed sections of the industry voluntarily accept a system of control by existing authorities to enable a younger section to operate more successfully, to the general advantage of the community. Second: that there are men within this industry capable of regulating its own affairs.

The other Committee is the Wiring Regulations Committee, which, for over 50 years, has been doing valuable work in preparing and publishing Regulations for the electrical equipment of buildings. It was set up originally by the Council in 1882 to draft rules for the prevention of fire risks arising from the use of electric light, and it has issued 10 successive editions of Regulations, each one adapted to the advances made in electrical engineering as applied to consumers' installations.

ELECTRICAL INDUSTRY

The growth of the electrical industry is reflected in the figures shown in Table 2.

In some cases exact particulars are not available; the estimates which have been made for calendar years are only for the purpose of showing the trend of development.

I cannot pass from these figures of electrical progress without referring to the important part played by the technical Press in the development of the industry, and its loyalty to The Institution. The high standard it maintains in the distribution of engineering, economic, and commercial information, has earned the regard of British engineers throughout the world.

REGULATIONS AND SAFETY

My remarks concerning the I.E.E. Wiring Regulations will be brief. The Regulations are the product of a large and fully representative Committee, and, as a result, are generally and voluntarily adopted as a standard of safe and sound wiring practice throughout the industry. They have been adapted to meet new inventions and developments from time to time, and have been used by the industry in general for over 50 years. The Eleventh Edition will be available next year.

The Council and Committee are fully aware of the importance of keeping the Regulations level with, and to some extent in advance of, progress. One of the chief difficulties in drafting them arises from the effort to cover five or six systems of wiring, for a dozen or more types of buildings, in a single set of Regulations. I have for some time held the view that a shorter and simpler set of Regulations is needed, and I hope that after the issue of the Eleventh Edition the Committee will give consideration to something of this kind.

There are four other sets of Regulations that affect installation work in buildings:—

(1) The Electricity Commissioners' Electricity Supply Regulations, 1934, for Securing the Safety of the Public and for Insuring a Proper and Sufficient Supply of Electrical Energy.

(2) The Home Office Regulations for the Generation, Transformation, Distribution, and Use of Electrical Energy in Premises under the Factory and Workshop Acts.

(3) The Home Office Regulations, 1923, under the Cinematograph Act, 1909, to secure the safety of audiences in cinematograph theatres.

(4) Regulations by local authorities for places of public entertainment and theatres.

I shall deal with only two points in the Commissioners' Regulations, the first being voltage tolerance, and the second the balancing of load between phases on alternating-current systems, and between outer conductors on what remains of direct-current systems.

In connection with the first it is very satisfactory to notice that, although voltage tolerance has been raised from 4 per cent to 6 per cent, supply undertakers realize the importance of keeping near to their declared pressure for the efficient working of apparatus, and in very few instances is advantage taken of the additional variation now permitted.

With regard to the second, the allowance of a minimum of 15 kW per phase, or per side of a three-wire direct-current system, has made it possible to reduce the cost of installations and services and to improve the safety factor.

The introduction of medium voltage into domestic buildings should be subject to the greatest care, and in no circumstances should medium voltage be introduced into a room where there is any possibility of portable apparatus being used on more than one phase. It is not enough to keep socket-outlets 6 ft. apart, or even 20 ft. apart, since vacuum cleaners, in particular, are often fitted with long flexible cords to extend over the whole area of a room. Vacuum cleaners fitted with earthing terminals and earth continuity conductors are only a small percentage of the whole, and the same applies to portable lighting fittings and small appliances.

A problem always arises when heating and cooking equipment is installed on premises where lighting already exists, but I suggest that, if it is necessary to balance phase against phase where the load exceeds 15 kW, only fixed apparatus with efficient earthing should be employed on one phase in the room where the second phase is introduced.

The Home Office Regulations under the Factory and Workshop Acts were first issued 27 years ago and have not since been revised. Explanatory memoranda on them remain substantially as issued in 1909. A revision would be welcomed by the industry, particularly if prepared in consultation with engineers responsible for working under those Regulations. The separation of generation, transformation, and distribution, from factory installation and equipment does seem desirable.

The Home Office Regulations under the Cinematograph

Table 2

	Great Britain and Ireland	Great Britain and Northern Ireland	
	1910	1922	1935
Electricity Supply			
Total units sold	1 027 millions	3 678 millions	14 692 millions
Lighting, heating, cooking: units sold (estimated)	150 millions	650 millions	5 000 millions
Total consumers connected (estimated)	300 000	1 200 000	7 500 000
Total consumers connected during the year (estimated)	30 000	200 000	800 000
Telephones			
Total telephones	647 000	1 060 000	2 520 000
Telephones connected during the year	45 900	75 000	183 100
Radio			
Radio receiving licences	—	125 000	7 381 000

Act are now being revised by the Department concerned, in consultation with the section of the industry directly interested.

Regulations adopted by local authorities for places of public entertainment are well administered by some authorities, but badly by others. In this connection we have the satisfaction of knowing that the Advisory Committee to the Building Industries National Council, on which The Institution has two representatives, is pressing the Minister of Health to replace the varying sets of local Building Regulations, of which there are over 1 000 in existence, by standardized Regulations with a minimum of legislative control.

We, in the electrical industry, have a healthy habit of criticizing our Regulations, and I propose to produce evidence to show that, thanks largely to our own Wiring Regulations, the safety of the public is well taken care of.

Table 3 gives a few figures regarding fatalities from various causes in 1934, taken from the Registrar General's Statistical Review for England and Wales.

The figures given in Table 3 show not only that users of electricity are well protected, but also that electricity is saving lives which might otherwise be lost. We have also on the credit side the lives that are saved through the use of electricity for communications and in medicine, for which no figures are available.

Table 3

Burns and conflagrations (excluding those due to gas and electricity)	897
Falling downstairs	738
Scalds..	453
Mechanical suffocation	411
Building operations	244
Coal gas—accidental or of unstated nature ..	165*
Falling out of bed	92
Electricity as primary cause	71

* Excluding 1 853 suicides and 13 murders which might not be considered to form a reasonable comparison.

ELECTRICAL INSTALLATIONS

The main practical purpose of my Address is to draw attention to the importance of providing adequate electrical installations in buildings. It is for ultimate service in buildings (apart from its uses in traction and street lighting and the like) that electricity is generated and distributed. The telephone services of the country are also almost entirely used in buildings, and the same applies to the receiving of broadcast programmes. The figures shown in Table 4 indicate the estimated cost of materials, with labour, installed and connected in buildings both old and new (excluding industrial plant), in 1934. These figures are estimates of the cost to the user. They have been compiled from Board of Trade returns and with the assistance of the sections of the industry concerned.

The generation and transmission of electricity are now entirely taken care of, as regards construction and operation, by the Central Electricity Board.

Local distribution has been the subject of an inquiry by a Committee set up by the Government, and a comprehensive Report has been issued. As a result, the industry and consumers hope that means will be found to give the whole country the advantages of complete electrification, under far-sighted management, as already exists in some areas.

The next step in development concerns the consumers' premises, where so many variables have to be considered and so many problems have yet to be overcome. We here arrive at the bottle-neck in the flow of electricity from the grid supply to the consumers' apparatus. This bottle-neck is most pronounced in domestic and commercial buildings, as extensions and alterations in factories are more easily made.

The system of living and working in buildings to-day demands service as well as floor-space and shelter. Yet we find that buildings of all kinds are being erected in this country with little consideration for those electrical and other modern services which must inevitably be required. These buildings are usually expected to have a useful life ranging from 25 to 50 years or more, and the electrical equipment is often found to be inadequate, even before they are occupied.

Table 4

Estimated Cost of Electrical Installation Work and of Apparatus installed in Buildings, 1934.

	£
Wires, cables, conduits, wiring accessories, and labour for installations in all classes of buildings	18 065 000
Apparatus, lighting fittings, vacuum cleaners, fans, irons, refrigerators, heaters, cookers, accumulators, signs, and other apparatus	9 800 000
Electric lamps (20 volts and over)	5 056 000
G.P.O. telephones—wiring and equipment..	1 464 000
Private telephone installations	400 000
Radio apparatus	26 350 000
	£61 135 000
House service meters	£2 307 000

Electrical installations in buildings began with wiring for lighting and bells, principally in wood casings, concealed from view as far as possible. In wiring older buildings to-day, metal-sheathed cables, tough rubber cables, or V.I.R. wiring in steel conduits, are used for all the services that electricity provides. New and larger buildings are being erected all over the country, and in these we encounter our chief difficulties. No longer is there room to tuck away wires, cables, and equipment just anywhere so as to be out of sight. The modern steel and concrete buildings of to-day, when once completed, become almost impregnable fortresses against electrical services.

The old custom of erecting the carcase, then knocking it down again in parts to accommodate the wiring, and afterwards patching up the fabric, is dying too slowly. It leads to additional builders' work, which is euphemistically called " cutting away and making good." This is expensive and the installation engineer is blamed for it. Cutting into the structure often weakens it, and the Building Research Station is collecting information on this aspect of the problem.

Some figures have been prepared for me by a number of quantity surveyors, whose chief work is to check the costs of buildings. These show that the cost of "cutting away and making good" averages approximately 10 per cent of the electrical installation cost. Diversion of this expenditure to cover additional attention to planning and providing the services in the building would represent an appreciable overall saving; further saving would result from the much needed acceleration of building availability.

A further point is that it nearly always happens that the first tenders for a complete building exceed the original estimated costs and something has to be omitted. More often than not, it is the services which suffer.

In view of the large amount of building in progress in the country, and the likelihood of its continuing for many years to come, it seems desirable that the electrical industry should give more attention to this matter and assist as far as possible in making buildings truly useful and efficient from the time they are occupied until they are finally pulled down, or at least for the first 25 years.

The value of new buildings erected in Great Britain during 1935 is estimated to be as follows:

	£
Houses and flats	161 639 000
All other buildings..	106 783 000
Total	£268 422 000

Figures which I have obtained of the cost of electrical wiring, equipment, and apparatus, relative to the total cost of buildings—taking all types, including factories—range from 1½ per cent for small cottages to 15 per cent for cinemas, with an average of 7½ per cent for houses, flats, and other buildings. This gives an approximate total of £20 000 000 for electrical equipment, in new buildings alone, in 1935. Industrial plant and radio sets are not included in this calculation.

With a view to showing in another way the importance of electrical services in buildings, I have obtained some figures for the consumption of electricity and the number of telephone-calls in certain large buildings, and, when compared with the corresponding figures for some fairly large towns, the results are striking.

A large store

Annual consumption	7 250 000 units, i.e. equal to such towns as Weymouth, Perth, or the whole of the Isle of Wight
Annual outgoing telephone calls	equal to the town of Tonbridge

A large block of offices

Annual consumption	1 016 000 units, i.e. equal to such towns as Stroud or Penzance
Annual outgoing telephone calls	equal to the town of Newhaven

A large hotel

Annual consumption	2 250 000 units, i.e. equal to such a town as Yeovil
Annual outgoing telephone calls	equal to the town of Dorchester

A large block of residential flats

Annual consumption	1 500 000 units, i.e. equal to such a town as Lewes

There are other buildings, such as stores and hotels, with a consumption of 5 million units per annum, and none of these can be described as fully equipped electrically.

I hope I have made clear the importance of planning installations concurrently with the planning of a building. In towns and cities, streets may be pulled up and traffic diverted for the extension of cables, and the man or woman in the street rarely complains; but these same persons will not tolerate the inconvenience of having floors taken up or walls disturbed for electrical extensions in their own homes and businesses, the consequence being that in many cases little or nothing is done. Channels, ducts, and conduits for the reception of wires and cables, must therefore be considered as an integral part of the building of the future, from the point of intake to the outlets.

The electrical load in most large buildings to-day makes necessary the provision for a local substation at the intake, in order to ensure continuity of supply in the event of the breakdown of a feeder and to enable adjacent small consumers to be supplied.

This question of substation provision is of major importance in modern electrical distribution, and makes necessary a continual survey of buildings, old and new, on the part of the supply undertakers concerned. Careful and tactful negotiations with architects and owners are called for. In some districts the problems seem to be overcome with ease, but in others they cause unending anxiety. Physical conditions often present difficulties, and success depends greatly on goodwill and understanding between the parties concerned.

From the supply undertaker's substation, the low-tension cables are taken to the main switch-room, in which sufficient space should be allowed for ease of operation of the switch and fuse-gear installed, and for repairs when required. From this room, vertical and horizontal channels or ducts should be provided to all local distributing centres. It is usually beyond these local centres that weakness of planning becomes most evident. It is just as important to have adequate runs of ducts and conduits from the local distribution centres as from the mains.

In the United States and Canada, underfloor duct systems have been adopted as standard practice in the wiring of nearly every type of building, except dwelling houses, for over 10 years. They have been used in this country, but only in a very few instances. The ducts are made of steel or fibre and are laid in the floor during construction. Some of them can be tapped at any desired position along the run, and others—the steel ducts—are fitted with inserts or outlets at predetermined distances in the duct run, usually from 2 ft. to 4 ft. One-, two-, or three-duct systems are employed, depending on the services required. The three-duct system is more generally used, as it provides more adequate facilities for services, and is installed:

for telephones and signalling wires .. in duct No. 1;
for heating and power .. .. .. in duct No. 2;
for lighting .. .. in duct No. 3.

The fibre duct, which can be tapped anywhere in its length at any time after installation, suffers from the handicap that it is more liable to damage during building operations. The steel duct is more robust and can be designed to stand up against rough handling incidental to modern building operations. Fig. 1 shows duct dimensions and Fig. 2 shows service fittings. The British Standards Institution has recently set up a committee to standardize steel underfloor ducts and accessories, and the Specification should soon be available for general use.

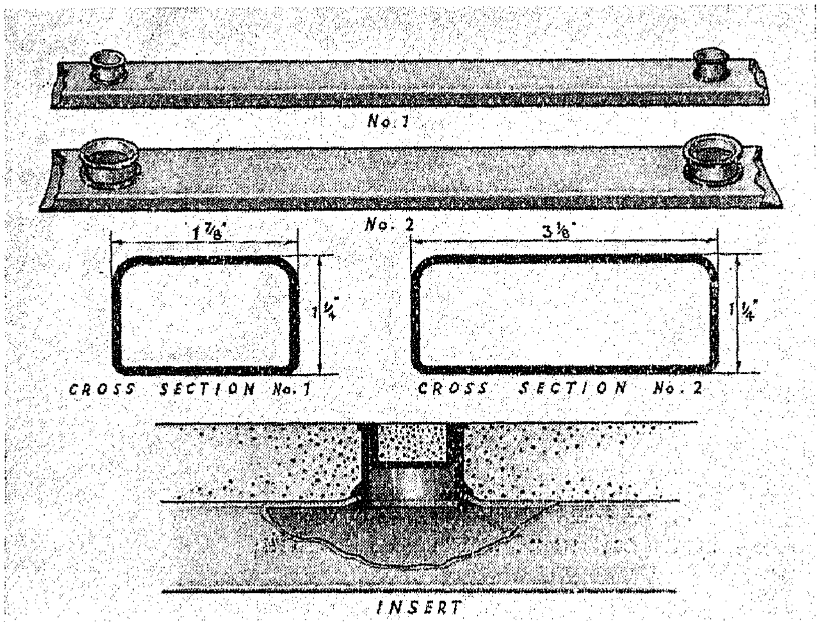


Fig. 1.—Under-floor duct.

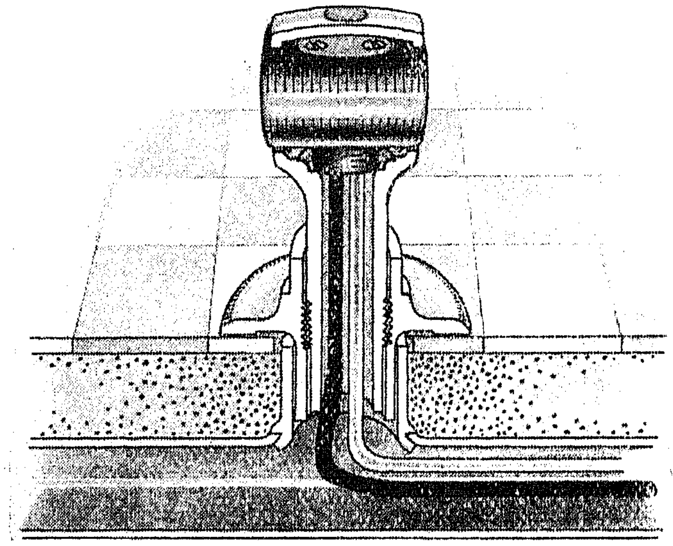
Fig. 3 shows various types of floor construction. The first is the simple single-joist wooden floor, followed by various types of reinforced concrete floors. The last example shows a new type of construction which has been invented and used in the United States, and which is receiving considerable attention from steel manufacturers at home. It is of cellular steel design to take the floor weight and the electrical wiring as well. This is an indication that there is still room for invention in building construction.

Fig. 4 shows various types of partition walls in general use. It will be readily seen how difficult it is to obtain adequacy and flexibility for the increasing number of wires and cables for electrical services to-day, if we are to continue to conceal them from view.

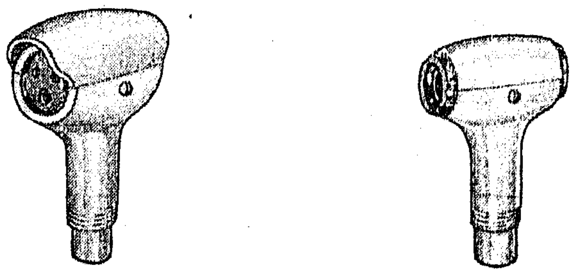
I have stressed the advantage of underfloor ducts for final wiring distribution, as I consider them essential to adequacy and flexibility in installation development. In addition to this suggested new development, some of the ingenious methods already adopted in modern buildings will have to be employed.

As an example of an installation where the electrical engineer and the architect have planned their work together, I should like to mention the new building for London University in Bloomsbury. This is probably the most interesting building in course of erection in the country to-day, and it seems to me to have the most complete electrical installation, as the lighting, space-heating, water-heating, and many other services, are all electric.

To make provision for the run of installed and future conduits all steel floor-beams have been drilled, during fabrication, with holes spaced to permit easy runs of conduit. In addition, provision has been made in the form of a 4½ in. brick chase on each side of all windows throughout the building from basement to roof.



Outlet



Socket outlet

Cable outlet

Fig. 2.—Service fittings.

A specially constructed cable trench runs round the basement of the building, along the base of all walls, and the conduit and cable runs are taken from this trench to the vertical chases by the windows.

This building is constructed to stand for some hundreds of years, and considerable vision has been displayed in designing the interior and the technical services, so as to permit maximum flexibility and ease of control throughout the life of the building.

A further example is the recently completed building for the Royal Institute of British Architects. This is another all-electric building, comprising electrode boiler with thermal storage and many other modern electrical features.

Before leaving the subject of supply services to large buildings, I wish to make a few general observations.

The policy adopted by some supply undertakers of installing mains to flats at no cost to the builder, or consumer, as is done from the street to private houses, could be followed with advantage throughout the country.

A closer study of load factor and diversity factor in individual buildings, and the interchange of information obtained throughout the industry, are a necessary step in electrical development. In some cases which I have recently investigated, the diversity of these diversities has been pronounced, and in many instances a knowledge of the general facts might lead to a rapid improvement in these factors, particularly in large domestic buildings.

When modern flats include a restaurant, it is just as important to install electric cooking in the restaurant kitchen as in the flats. The tendency in these buildings is for the tenants to have meals in the restaurant or delivered to their flats, and electricity's competitors seem to be well informed about these conditions. As an instance, in one large block of all-electric flats, the load could be increased by 500 000 units per annum, i.e. over 30 per cent, if the restaurant kitchen used electricity.

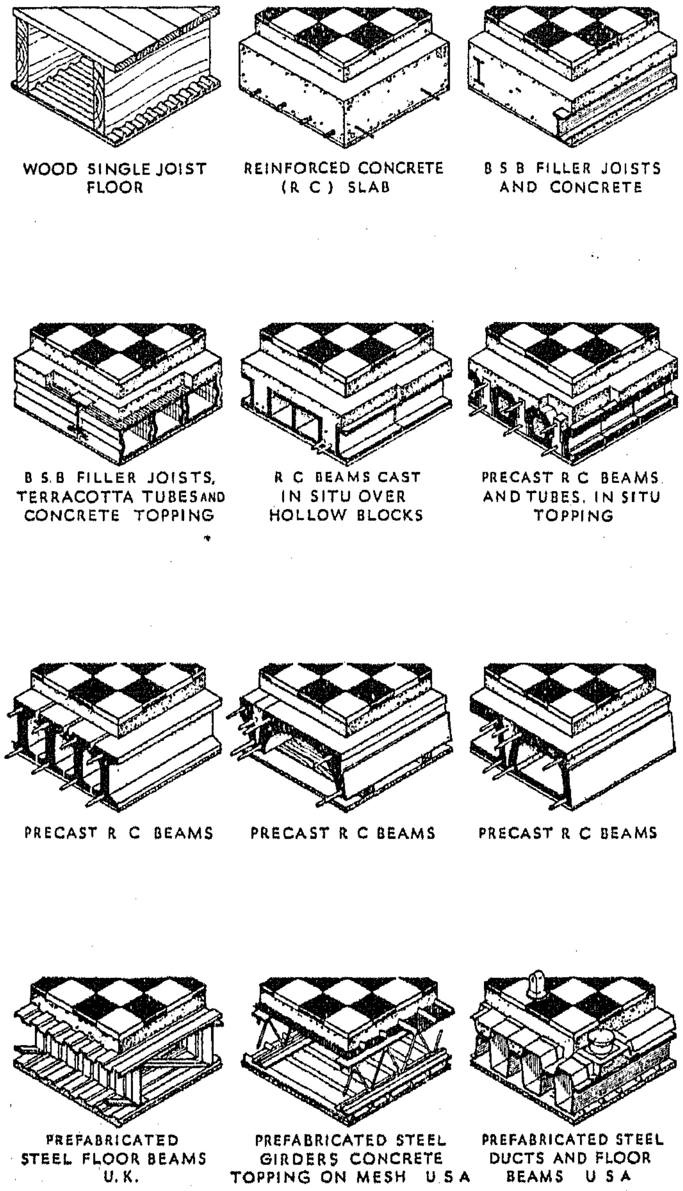

WOOD SINGLE JOIST FLOOR
REINFORCED CONCRETE (R C) SLAB
B S B FILLER JOISTS AND CONCRETE
B S B FILLER JOISTS, TERRACOTTA TUBES AND CONCRETE TOPPING
R C BEAMS CAST IN SITU OVER HOLLOW BLOCKS
PRECAST R C BEAMS AND TUBES, IN SITU TOPPING
PRECAST R C BEAMS
PRECAST R C BEAMS
PRECAST R C BEAMS
PREFABRICATED STEEL FLOOR BEAMS U.K.
PREFABRICATED STEEL GIRDERS CONCRETE TOPPING ON MESH U S A
PREFABRICATED STEEL DUCTS AND FLOOR BEAMS U S A

Fig. 3

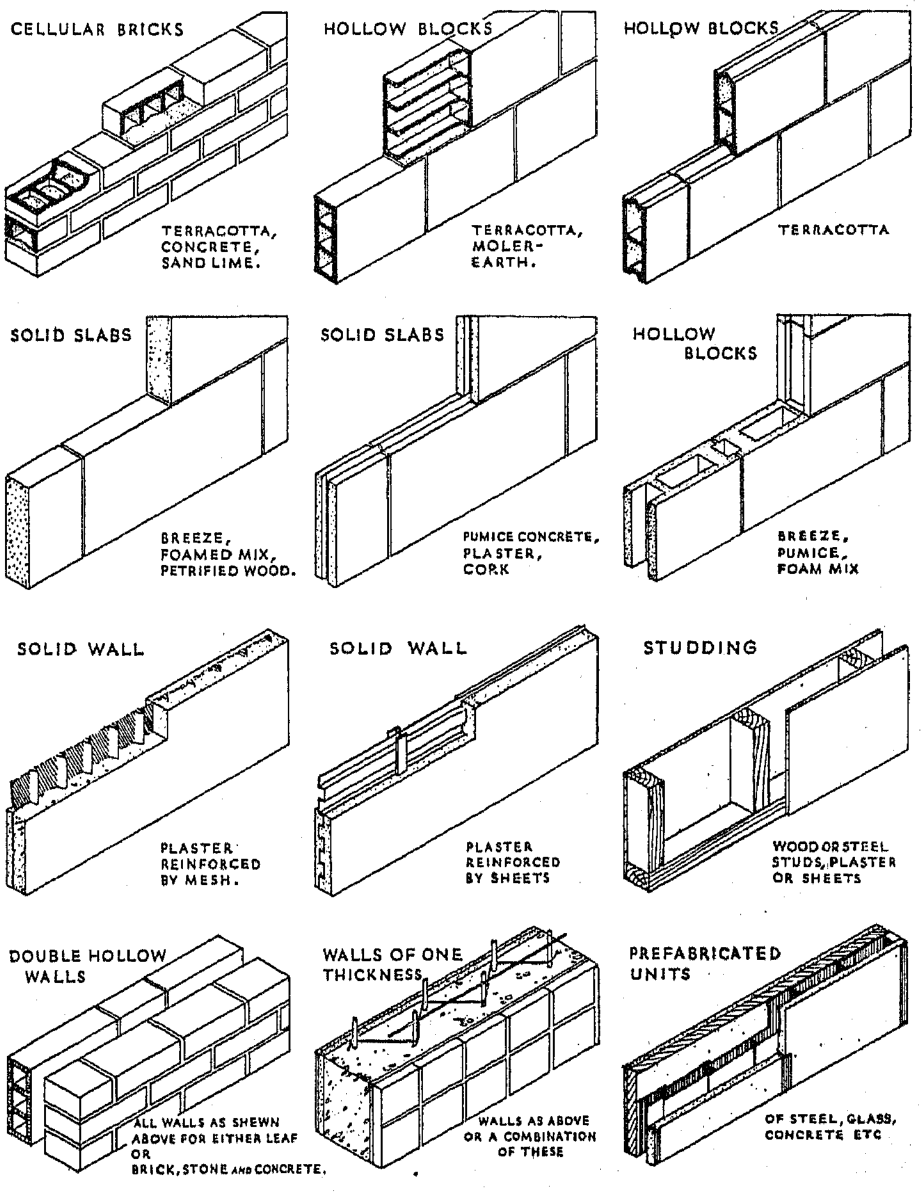

CELLULAR BRICKS
TERRACOTTA, CONCRETE, SAND LIME.
HOLLOW BLOCKS
TERRACOTTA, MOLER-EARTH.
HOLLOW BLOCKS
TERRACOTTA
SOLID SLABS
BREEZE, FOAMED MIX, PETRIFIED WOOD.
SOLID SLABS
PUMICE CONCRETE, PLASTER, CORK
HOLLOW BLOCKS
BREEZE, PUMICE, FOAM MIX
SOLID WALL
PLASTER REINFORCED BY MESH.
SOLID WALL
PLASTER REINFORCED BY SHEETS
STUDDING
WOOD OR STEEL STUDS, PLASTER OR SHEETS
DOUBLE HOLLOW WALLS
ALL WALLS AS SHEWN ABOVE FOR EITHER LEAF OR BRICK, STONE AND CONCRETE.
WALLS OF ONE THICKNESS
WALLS AS ABOVE OR A COMBINATION OF THESE
PREFABRICATED UNITS
OF STEEL, GLASS, CONCRETE ETC

Fig. 4

Telephone Installations

The planning of telephone installations has now to be done along with that of other electrical services, although the wiring must be kept apart.

The General Post Office published in 1931 a book giving descriptions and illustrations of methods of installing cables and apparatus in buildings, and this book was circulated to all architects in the country. The time has come to revise it, and the General Post Office Engineering Department is collaborating with the Electrical Development Association in the hope of producing a comprehensive publication dealing with all electrical services.

Radio Installations

Radio reception has now become so well established in the life of the community that provision must be made in large buildings, especially blocks of flats, for this comparatively new service. Two methods are in general use. One provides for each building a central aerial system from which aerial and earth wires run to each flat so that the tenant may use his own receiver. The other—the relay system—provides a central receiving station for one or more buildings, from which a pair of wires carrying amplified currents is taken to each flat for each programme provided. The flat equipment in this case consists of a loud-speaker only.

Arrangements must also be made for the reception of television programmes, and already, in a block of flats in London, both sound and television programmes are taken from one central aerial system and distributed by cables to a terminal box in each flat, from which the tenant may receive both services on his own equipment through a socket-outlet and plug attachment. For this purpose, a special "co-axial" type of cable, capable of carrying the extremely high frequencies required for television, is used.

The estimated total annual consumption of all-mains radio sets is 300 million units—equal to twice the estimated load in 1910 for lighting, heating, and cooking.

Most of the time at my disposal has been devoted to larger buildings, as in the present stage of electrical progress it seems to be the direction in which most attention is required; but I cannot leave the subject of the wiring and equipment of buildings without mentioning the good work that is being done all over the country to place electricity at the service of our fellow men and women whose earnings permit them to spend only a few shillings per week on lighting, cooking, wireless, and the like. Reports are available of developments in West Ham, St. Pancras, Westminster, Chester, Bedford, and other places equally important but too numerous to mention here, containing evidence of the desire of the small wage earner to obtain electrical service, and of the ingenuity of the engineers responsible for installing the equipment.

The operation of the Housing Act of 1935 for the abatement and prevention of overcrowding will be responsible for accelerating the building of small houses in 1937 and the following years. A survey has been made by local authorities and it is estimated that 200 000 new houses will be required in England and Wales and 150 000 in Scotland. A special study on a national basis for providing electrical facilities for this development seems desirable.

The potential load in houses of the class that lies between the minimum consumer and the large building is well known to all engineers, but, as one example of what can be expected, I cannot do better than refer to a paper read before this Institution in 1923 by Prof. Parker Smith, on his own electric house in Glasgow. The author has kindly given me these figures. For the first year, 15 441 units were consumed at a cost of £41 13s. 11d., and last year the figure was 24 923 units at a cost of £36 2s. 1d., the consumption having increased by 60 per cent and the cost per unit decreased by nearly 50 per cent.

LIGHTING

Chiefly on account of the good work that has been done by the Illuminating Engineering Society and the Electric Lamp Manufacturers' Association, the subject of lighting has not received from The Institution the attention it deserves. Good as the work is that has been done elsewhere, I think that lighting by electricity must, sooner or later, occupy a more prominent position in this Institution's work.

The new discharge lamp which Mr. Paterson described and exhibited in his Presidential Address in 1930 has been developed commercially for street lighting, and for this purpose it is rapidly superseding all other systems. Its use for interiors has, so far, been chiefly for factory lighting, but the most recent research on this type of lamp indicates that before long its usefulness will have a very much wider range.

The output of incandescent lamps increases year by year. In 1934 the number used in Great Britain was 64 millions, and in 1935 it was 67 millions. This growth in output is brought about by the necessary increase in intensity in artificial illumination, and by the closer study of the design of lighting installations. Stores and shops are leading the way to better lighting, with intensities up to 60 and 80 foot-candles. I know of one installation where the lighting load is 1 200 kW, for an area of 15 000 sq. ft., with a load factor of about 25 per cent, the light being used all day. To achieve these high intensities without glare, it is necessary to conceal the light source from the eyes and, at the same time, reflect direct light on the working plane. This is done by a combination of reflectors and louvres fitted into or immediately below the ceiling.

The people of this country are expecting light to be one of the greatest attractions in the Coronation celebrations next year. This, together with the experience gained in the art of flood-lighting in the past five years, will encourage electrical engineers throughout the country to be unsparing in their efforts to surpass even the highest expectations of the public. The 12th May, 1937, is not far distant, and the resources of the industry will be heavily taxed when the time draws near. Where plans have yet to be made, no further time should be lost.

DESIGN OF APPARATUS

In the design of apparatus there is still much room for improvement. The copying of old forms and shapes in lighting, heating, and cooking apparatus served a useful purpose on the introduction of electricity into domestic and everyday life, but to-day everything we manufacture should carry with it a sense of fitness. The turbo-alternator is a fine example, with clean and efficient lines and no suggestion of anything superfluous.

Modern electric cookers should now be manufactured in a more pleasing form, and should be combined with other kitchen equipment so as to make up an interesting domestic workshop for the home, of which the housewife may be just as proud as she is of her dining-room. This has been done successfully in the United States and Canada, and we have to remember that these countries were mainly responsible for introducing some of the earlier domestic apparatus, such as refrigerators and vacuum cleaners.

Built-in fires of good design have already established themselves, and the design of lighting fittings has undergone a complete change for the better, but there is still much opportunity for imagination and invention in connection with apparatus. It is essential that manufacturers should make greater use of trained and skilled designers in order to keep pace with other domestic applications. Electricity provides the most modern service, and it seems only logical that the equipment which it operates should be equally up-to-date. Premises on which electrical apparatus is displayed to public view and inspection should inspire the sense of seeing, just as the thought of the great purpose to which electricity is devoted inspires the imagination.

We continue to use cumbersome and ugly cast-iron cases for light efficient switch and fuse gear, when they could be equally well housed in pressed-steel cases of one-quarter the weight, with a saving in cost of transport and fixing and a vast improvement in appearance.

A new piece of apparatus known as a " kitchen waste unit " has recently been introduced. This will crush and pulverize all garbage and waste from the home and send it direct into the house drain and sewer, thereby dispensing with the antiquated and insanitary dustbin, which is a disgrace to 20th century civilization.

STANDARDIZATION

History has taught us that progress in design and operation is continually to be expected. Therefore it behoves us to be watchful and critical of standardization; but there are certain directions in which the importance of standardization should never be in doubt because of the primary purpose it serves, namely, interchangeability.

First .. Voltage and frequency of supply.
Second .. Lampholders and lamp caps.
Third .. Plugs and socket-outlets.

The last-mentioned is the latest standard to be embodied in a British Standards Specification. The manufacturers who are discarding their own designs in favour of the new standard are doing a great service to the industry. The chaotic conditions due to lack of standardization are a source of annoyance to consumers, and are wasteful in time and money to those concerned in the practical equipment of buildings and the supply of apparatus.

EDUCATION AND TRAINING

At no time in our history has more attention been given to the education and training of young men, and at no time have those concerned with the education of young electrical engineers been more prepared to learn from industry what it requires. In the past, the larger manufacturers were, to a considerable extent, depended upon for a lead and for assistance in the training. To-day they are still doing their share, but something more or something different is required to train men to be, first, electrical engineers, and then to be adaptable to some form of commercial training as well. This is especially necessary for the consumers' engineers in the employ of supply undertakers and for contractors' engineers, who are in continuous contact with the users of electricity and electrical apparatus. It is on these men that so much will depend in the next decade.

The industry cannot leave to men with only commercial training the work of advising consumers on the wider and better uses of electricity. The consumer always prefers to discuss his problems with a technical man who is able to advise him intelligently, and he rarely has confidence in anyone else.

The organized sections of industry concerned may be able to advise and assist our technical schools and colleges. The problem is important and urgent. It would certainly be helpful if our colleges were to add to their staffs a lecturer with a good knowledge of industrial research work.

An extract from Sir Thomas Purves's Inaugural Address in 1929 is particularly appropriate here:

" Every branch of the electrical industry should be prepared to train the young men who enter its ranks. . . . It means appreciable immediate sacrifice on the part of employers, but in the ultimate interests of progressive national efficiency it is richly worth while."

The payment and prospects of the commercial engineer should be made so attractive that the best and most suitable men will be drawn to this section—men capable of holding ultimately the highest positions in our industry.

The Electrical Contractors' Association is doing good work in encouraging its members in the training of apprentices as electricians and electrical wiremen. The period of training is usually five years, in which the apprentice goes through all classes of installation work and is expected to attend evening classes during the winter months. This system is continuously providing skilled men in large numbers, many of whom advance to higher positions.

The training of women is guided chiefly by the Electrical Association for Women, in which the industry has complete confidence. Women have earned the responsibilities they now carry in domestic electrical development, and they deserve full recognition for their services.

CONCLUSION

It might have been of greater interest to you, and more enjoyable to me, if I had described some of the most recent electrical applications in buildings and their influence on our daily life, but in the time at my disposal I have endeavoured to direct attention to matters that seem to me to be the most pressing in connection with the social and commercial utilization of electrical energy. I hope that in the near future papers will be read dealing with the mechanism of applications.

I have not touched upon the national responsibility of the electrical engineer, or examined his relationship to the present and future structure of society. We all know that this wider responsibility exists. We should remember that it is also realized and accepted, and we must accept it with a profound desire to understand the social problems that, from time to time, arise as the result of advances made in electrical science. To do this effectively we must have the assistance of other professions whose interests overlap or intersect our own. We cannot succeed without their help; and, in order to obtain that help, we must be able to comprehend something of their problems. Therefore I suggest, in conclusion, that from time to time this Institution should examine very carefully its relationship with other organizations concerned with the uses of electricity, even though in name they may not be " kindred societies." In this way, I am convinced, we shall continue to serve most faithfully and surely the great purpose for which this Institution exists—the advancement of electrical engineering science.

METER AND INSTRUMENT SECTION: CHAIRMAN'S ADDRESS

By G. F. SHOTTER, Member.

(*Address delivered* 6*th November*, 1936.)

INTRODUCTION

I should like to commence by expressing my appreciation of the honour which you have accorded me in making me your Chairman. I assure you that I shall fulfil my duties to the best of my ability.

I have chosen for my Address three subjects which I hope will have a wide appeal and be of interest to you.

First, I propose to describe a new method of transmitting the readings of an integrating meter to a distant receiver.

Secondly, I shall deal with a method of analysing the friction on meters returned from service.

Thirdly, I shall discuss the theory of the rotating or shifting field and the " transformer " theory as applied to induction meters and instruments.

(1) REMOTE INDICATION OF THE READINGS OF AN INTEGRATING WATT-HOUR METER

To the best of my knowledge all existing systems for the transmission of the readings of an integrating watt-hour meter over long distances make use of contacts in some form or other, with the exception of a method employing the photo-electric cell, used in the United States. The method I am about to describe is one in which no contacts are used and which I think will be of technical interest to you all.

The apparatus consists of (*a*) a watt-hour meter fitted with a special impulsing element, (*b*) an amplifying unit, and (*c*) a distant receiver.

Fig. 1 shows the transmitting portion of the apparatus. It consists of a loop which is arranged to couple inductively two field systems as it rotates.

One field system is energized from the potential circuit of the meter, and as the loop, which is mounted to the spindle of the meter, enters the field of this electromagnet, a voltage is induced and consequently a current is produced in the loop. In turn, this produces a voltage in the second electromagnetic system and thus a voltage is produced across the terminals of the second coil system. This voltage is applied to the grid of a gasfilled relay, the anode of which is supplied from the potential system of a small transformer, another winding of the transformer supplying the filament of the valve. The anode circuit is completed through the pilot wires to the distant receiver.

The distant receiver can consist of any standard impulse-receiving apparatus and may be arranged for simple remote indication, remote maximum-demand indication, remote maximum-demand recording, or, by using summation receivers, for corresponding summated values of a number of transmitters.

Fig. 2 illustrates the loop mounted to the spindle of the watt-hour meter transmitter. It will be observed that the loop is cut, in the form of a figure 8, from a flat disc, and is insulated at the hub.

Reference may now be made to some points of technical interest. The first is that, as arranged at present, the voltage produced at the output terminals of the transmitter increases from zero to its maximum value twice in each revolution, the period for the zero and maximum values being approximately equal. In order that the output of the transmitter may be used more effectively, boosting coils are added, with the effect that the maximum value of the output voltage is increased.

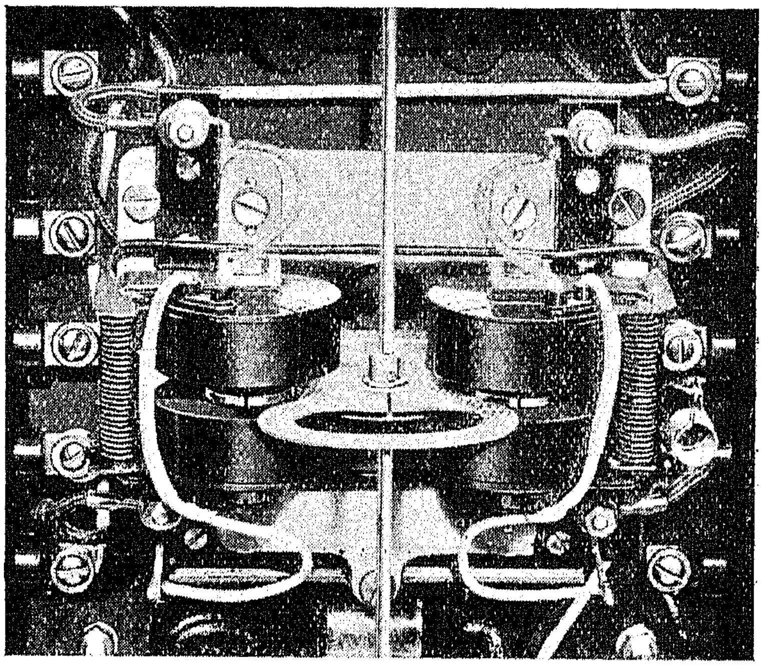


Fig. 1

Fig. 3 shows diagrammatically the result obtained with the boosting winding. This arrangement ensures that full use is made of the impulse voltage, amply covering variations in individual valves in regard to the ratio between their anode voltage and their grid voltage. The boosting voltage can be readily adjusted according to the required anode voltage to obtain the best performance of the apparatus.

Another point of interest relates to the effect of the special impulsing element on the performance of the watt-hour meter. The only appreciable effect is that the loop increases the starting current by acting in the manner of an anti-creep slot. Actually, the loop tends to be self-compensating, inasmuch as when it enters the gaps it is repulsed by the primary field system and attracted by the secondary field system. The reverse takes place as the loop leaves the gaps. These two forces, however, do not balance, and compensation is therefore applied in the form of a piece of iron, shaped in such a manner as to produce, in conjunction with the poles of the electromagnets, a force equal and opposite to that of the resultant force of the loop. This arrangement may be understood by again referring to Fig. 2. Thus the starting current of the watt-hour meter can be reduced to that required by the British Standard Specification.

Other details of technical interest are that the relay consumption of the transmitter and the amplifying transformer is approximately 14 VA; the system is practically independent of normal variations in voltage and frequency; and the maximum external resistance, i.e. that of line plus receivers, which can be dealt with, using an anode voltage of 200, is 10 000 ohms.

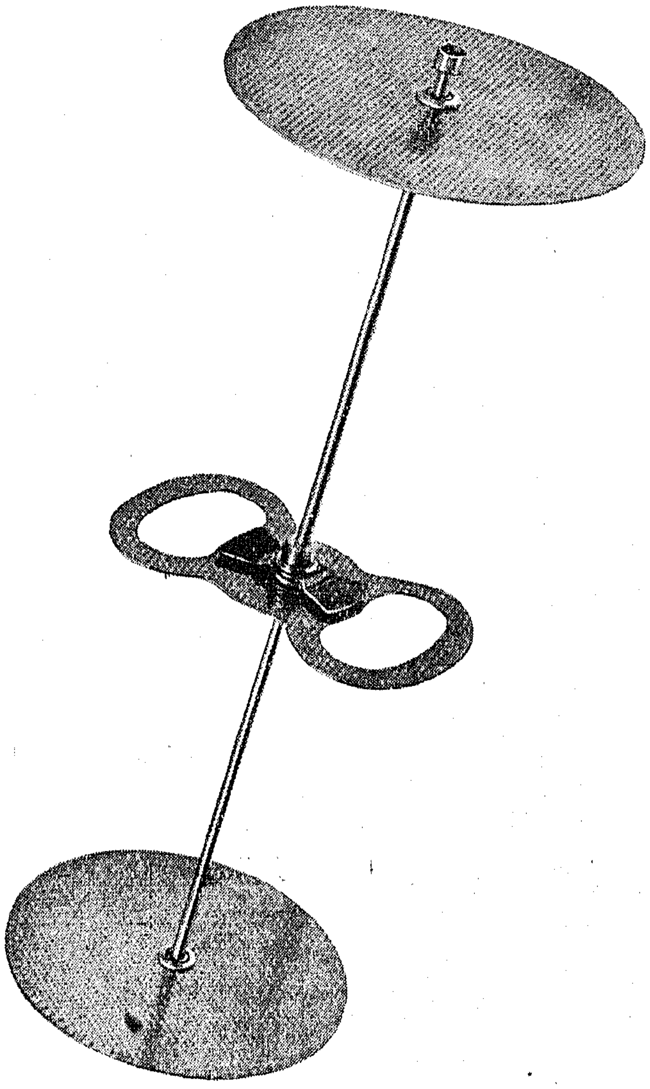


Fig. 2

The anode voltage used in one completed equipment was 100, with an anode current of approximately 30 mA. The valves may be either of the mercury or argon type and it will be seen that they are considerably underloaded, consequently a long life can be expected from them.

(2) A METHOD OF ANALYSING THE FRICTION ON METERS RETURNED FROM SERVICE

In view of the Meter Bill which has recently been passed, I think that a description of a method of analysing the friction on meters returned from service will be of practical interest.

One of the most important problems which every meter engineer has to face concerns the maintenance of accuracy of electricity meters. It is obvious that friction in meters operates against the interests of the supply authority. In a big concern it is not an economic proposition to test every meter returned from service before overhaul. It is, however, essential to obtain information on what may be termed the " average as received " condition. From this condition it is possible to obtain a fair estimate of the total average increase in friction.

A knowledge of the total average increase in friction, however, is only valuable up to a point. To take full advantage of this knowledge an analysis must be made, that is to say the various components of the total friction must be separated and definite information obtained regarding the proportion in which the friction is distributed among them and their possible cause. My own company obtains reliable figures by testing a definite percentage of returned meters every week to a fixed schedule.

As you are aware, friction can only occur at three particular points in the mechanism: (1) in the train, (2) in the top bearing, (3) in the lower bearing; and I am now going to describe a set of tests which we carry out in order to determine the proportion in which the total increase in friction is distributed among these components. All the tests are carried out at both 1/10th and 1/20th loads in the following order:—

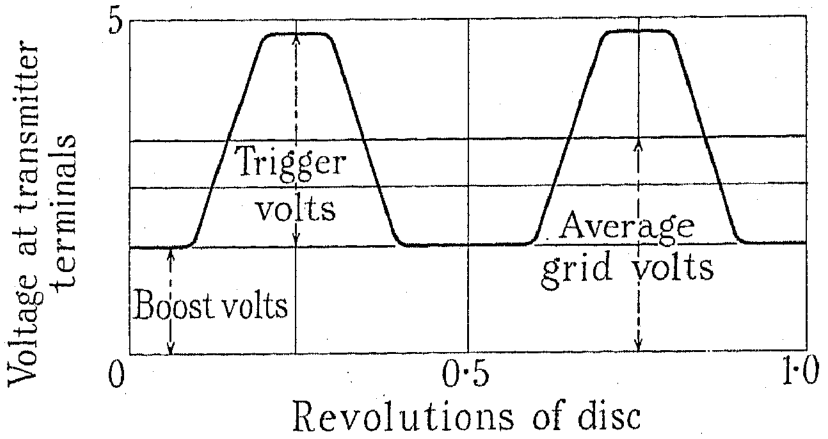


Fig. 3.—Output from transmitter coils.

(A) The meter is tested " as received."
(B) The top bearing is then cleaned and oiled, the clock and worm wheel remaining in their original condition, and a second test is taken.
(C) The clock is removed and the third test taken.
(D) The first reduction in the clock, i.e. the worm or pinion on the rotor shaft, and the first wheel on the clock, are cleaned and the fourth test taken.
(E) A new pivot and jewel are then fitted, or if oiled jewels have been used the combination can be cleaned and re-oiled, and the fifth test taken.

From these tests the proportion in which the friction is distributed may be obtained as follows:—

Test (A–B) = Increase in top-bearing friction under load, i.e. friction increase due to service.

Test (B–D) = Increase in clock friction due to service.
Test (D–E) = Increase in bottom-bearing friction due to service.

The sum of these errors, i.e. (A–B) + (B–D) + (D–E), should equal (A–E), i.e. the total increase in friction.

The other differences give the following friction figures:

Test (B–C) = Total clock friction "as received."
Test (D–C) = "Zero" clock friction. If this is higher than normal, friction in the third or fourth reductions of the train is indicated.

I would point out that as the top-bearing friction is influenced by the clock friction, it is difficult to separate completely the proportion between them, particularly when the clock friction is high, as the pressure due to side thrust increases and consequently the friction increases. This side-thrust effect of the clock drive is one of the reasons for taking the top-bearing friction test first. The results would be incorrect if the clock friction test were taken first, because, on account of the side thrust, part of the top-bearing friction would appear as clock friction. Consequently, the friction would be reduced when the clock was removed. Therefore the top bearing is cleaned first and, although its side thrust still causes an apparent increase in the clock friction, its effect is small since the total top-bearing friction is then small.

Table 1

Friction Analysis of Meters Returned from Service. Analysis based on 32 Type 1 and 30 Type 2

	Type 1		Type 2	
Load	1/10	1/20	1/10	1/20
Top-bearing friction, expressed in:—				
(1) Percentage error	0·3	0·4	0·2	0·3
(2) Dyne-centimetres	1·5	1·0	1·0	0·75
(Test A–B)				
Train friction:—				
(1) Percentage error	0·5	1·2	0·3	0·5
(2) Dyne-centimetres	2·5	3·0	1·5	1·25
(Test B–D)				
Bottom-bearing friction:—				
(1) Percentage error	0·2	0·2	0·3	0·3
(2) Dyne-centimetres	1·0	0·5	1·5	0·75
(Test D–E)				
Total friction due to service:—				
(1) Percentage error	1·0	1·8	0·8	1·1
(2) Dyne-centimetres	5·0	4·5	4·0	2·75
(Test A–E)				

Another reason for taking the top-bearing friction test first is that, before the clock friction test can be taken, the disc must be removed and thus the top bearing disturbed. In practice it was found that this altered the top-bearing friction, giving a false value to its friction figure. On the other hand, the effect of disturbance was found to be not so noticeable when dealing with either the pivot and jewel or the clockwork, the errors introduced being generally negligible.

I have mentioned the term "zero" friction in the foregoing tests, and I should like to say that this may be defined as the minimum possible friction under the best conditions, i.e. after cleaning and oiling.

Table 1 gives the results of these tests on 62 meters.

One interesting point which has evolved from this method of routine testing is that the friction due to service of the cyclometer type of train is approximately 3 to 4 times the amount found in the ordinary pointer type.

Another point of interest brought out is that the higher the initial friction the higher is the error produced for any given percentage increase in friction due to service. For example, let us assume that the initial clock friction is 1 per cent, which has presumably been allowed for in calibration. In this case an increase in friction of 100 per cent is equivalent to 1 per cent error on the meter, whereas if the initial friction were only 0·25 per cent a 100 per cent increase in friction would represent $\frac{1}{4}$ per cent error on the meter, demonstrating the importance of obtaining low initial friction.

In the case of my own company, the amount of information which has been gained from these tests, in conjunction with an observation of the components before and after cleaning, has led to considerable improvements, in that we have been able to evolve the best methods of cleaning and polishing the component parts to obtain the lowest possible initial friction and to minimize the increase in friction during service. We have also been able to ascertain the effect of service on the different metals used for components.

I have described this method as I think that our experience may be useful to others dealing with this serious maintenance problem.

(3) A DIGRESSION ON THE "ROTATING" OR "SHIFTING" FIELD THEORY VERSUS THE "TRANSFORMER" THEORY AS APPLIED TO ELECTRICITY METERS AND INSTRUMENTS

I doubt if I should have had the temerity to broach this subject if I had not known that it is the Chairman's privilege to expect no reply to his Address.

In order to present a clear picture it may be as well to start by defining the two theories which I am about to discuss.

The Rotating or Shifting Field Theory.—This assumes that the two electromagnetic fields which are produced by the respective shunt and series ampere-turns and which are out of phase with one another so combine in the air-gap that the resultant field moves with a definite velocity within the gap to produce eddy currents in the disc, and, by means of their interaction with this resultant flux, they produce a torque which causes rotation of the disc.

The Transformer or Induction Theory.—This assumes that eddy currents in the disc are produced by each component of the flux, these eddy currents in turn producing a torque to cause rotation by interacting on their "opposite" poles. Normally the two fluxes are 90 electrical degrees apart at unity power factor and produce in the disc eddy currents which are practically in quadrature with the flux producing them, owing to the disc being only slightly reactive. It follows that these eddy currents are either in phase or 180° out of phase with their "opposite" pole fluxes. As the path of these eddy currents lies within this flux area, they produce a torque to cause rotation of the disc. The action may be regarded as being identical with that of a dynamometer instrument, with the exception that the current in the moving conductor is produced by transformer action from the fixed electromagnets.

Two main reasons prompted me to discuss these theories. The first is that I have always viewed with concern the extraordinary variance which textbooks and handbooks show in their choice as to which theory they should propound. For example, one of the most comprehensive books on electrical instruments does not mention in any way the rotating or shifting field theory, whereas other well-known books mention both this and the transformer theory and leave the reader to choose between them. In fact, in one book the rotating field theory is mentioned as an explanation of the phenomena and is rejected in favour of the transformer theory when calculations are required of the torque. On the other hand, certain textbooks, including American, mention only the rotating or shifting field theory. This theory seems also to have predominated in papers before this Section from time to time.

The second reason for my discussing the subject is a personal one. This has been due to the fact that I have never been able to visualize the rotating or shifting field as having any physical reality as applied to electricity meters and instruments as generally constructed. I admit that it is a simple, I might even say lazy, way of explaining the phenomena. Indeed, I think that its very convenience has caused what I believe to be the true explanation to be neglected. In other words, the theory of a rotating or shifting field has always appeared to me to be more of a mathematical artifice than a physical reality, and it is possible that the originators of it were conversant with this view.

At the outset I wish it to be clearly understood that I am not suggesting that a true rotating field is not produced in, say, a 2- or 3-phase motor where the windings are interlaced and the air-gap is uniform in the direction of rotation. The construction which we are dealing with, however, is totally different in that the condition of uniformity is entirely absent.

You might perhaps appreciate the difficulty of visualizing the rotating field as a physical reality, taking the example, for simplicity's sake, of the separate electromagnetic design of instrument. You would have to visualize the existence in the gap of a field, which is the vector resultant of the two fluxes within the gaps, moving transversely from one pole across the interspacing polar gap to the other pole. This would mean that the reluctance of the interpolar gap would have to possess the same magnetic value as the main pole-gaps. Since this is not the case, as there is complete air separation between the electromagnets, the obvious conclusion would seem to be that only a small component of this resultant flux could shift or rotate.

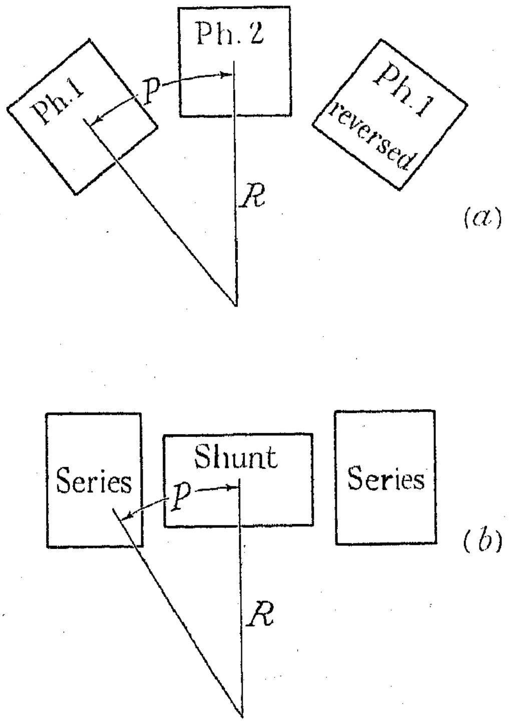


Fig. 4.—Method of determining "apparent" synchronous speed.

(a) Experimental model (with separate iron circuits). Calculated synchronous speed = 641 r.p.m.
(b) Typical watt-hour meter (with common iron system). Calculated synchronous speed = 516 r.p.m.

$$\text{Apparent synchronous speed} = \frac{2P \times f \times 60}{2\pi R}$$

Before describing my experiments on the subject, there arises the question of what would be the synchronous speed of this rotating or shifting field. There would appear to be only one method of determining this, i.e. by calculating the time taken for one cycle to traverse twice the polar arc.

Fig. 4 shows a diagram of this method. The actual value of the synchronous speed obtained from the model I am about to describe is approximately 600 r.p.m.

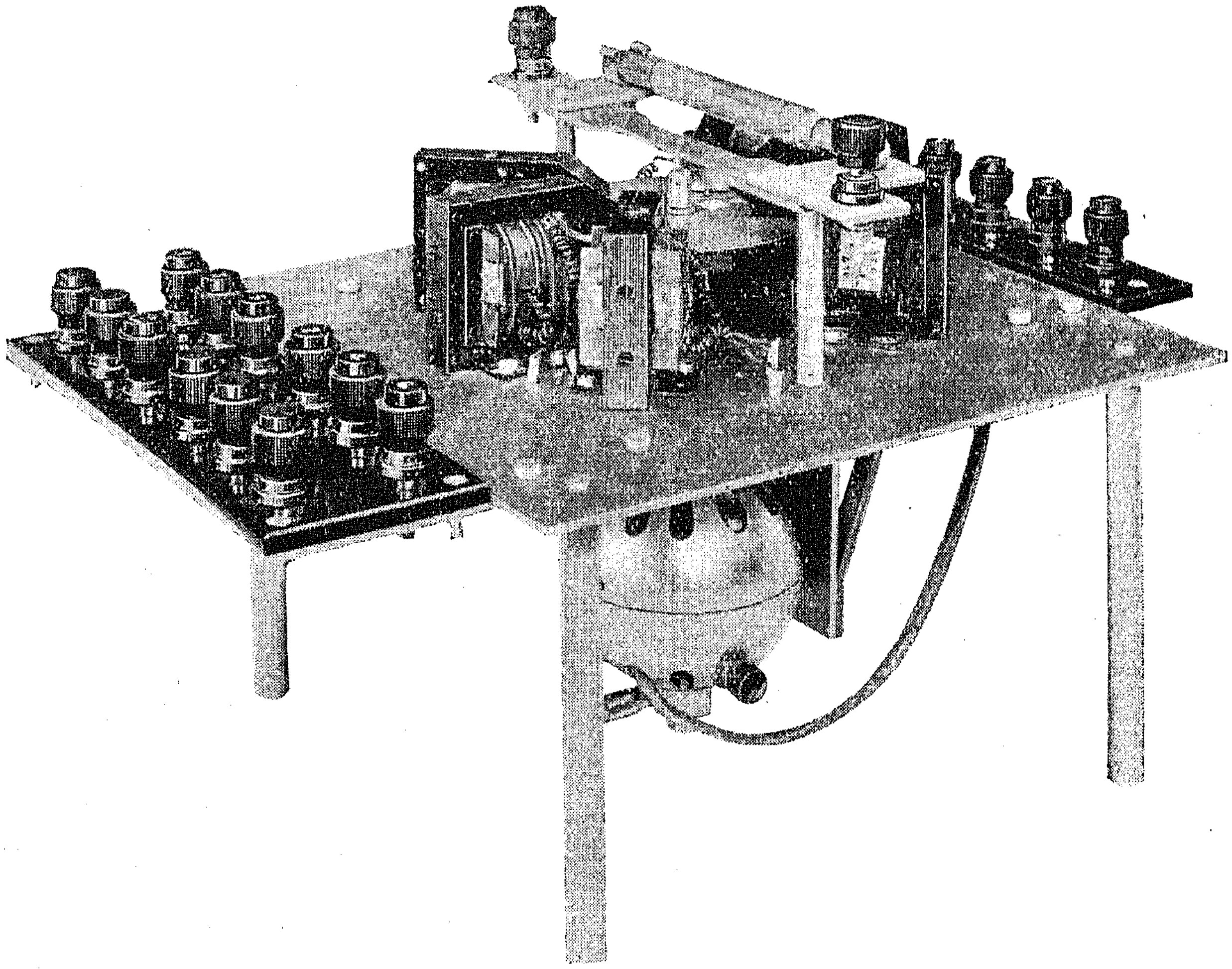


Fig. 5

To sum up the foregoing, it would appear that three assumptions exist:—

(1) That the whole flux shifts or rotates.
(2) That only a portion of the flux shifts or rotates.
(3) That no rotation or shifting occurs at all.

Only one of these assumptions could be correct and, after considering the matter, I decided to carry out experiments in an attempt to establish the physical facts and enable you to judge the true explanation of the phenomena.

A simple method of attacking the problem consisted of rotating a disc within the gaps of a suitable arrangement of electromagnets, the disc being driven by a small separately-excited d.c. motor, so that by measuring the watts taken by the motor at various speeds it would then be possible to determine the damping in terms of watts produced by the relative motion of the flux and the rotating disc. The method may be regarded as a means of chasing the rotating or shifting field, if it exists.

Now if the assumption that the whole flux shifts or rotates were correct, then the watt input of the motor at the synchronous speed would only consist of the losses of the unloaded motor at this speed.

On the other hand, if the assumption that only a portion of the flux rotates were true, then a departure from a curve obtained with the magnets excited by single-phase or direct current would be shown.

Finally, if the assumption that the flux does not shift or rotate were correct, one would expect the shape of the damping speed curve to have the same relationship for direct, single-phase or 2-phase current.

Fig. 5 gives a general view of the apparatus constructed to carry out these experiments. It consists of a small

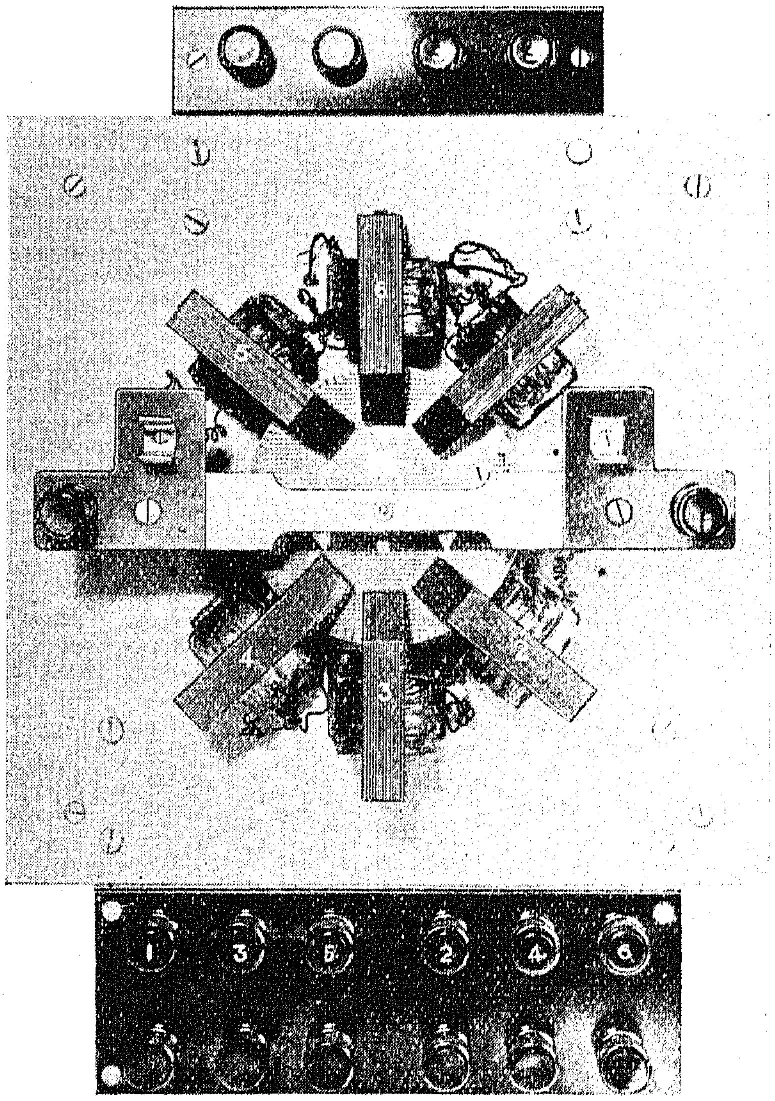


Fig. 6

d.c. motor coupled to a disc rotating between the poles of six electromagnets arranged in two sets, suitable terminal arrangements being made so that any combination of coils could be readily obtained. A neon lamp was fitted so that the speed of the disc could be determined stroboscopically, a fork being used for the purpose. In order to cut down the no-load losses of the motor, it was excited from a separate and constant source of supply in all the tests.

Fig. 6 shows a plan view, which conveys a better idea of the arrangement of the electromagnetic system. 100-volt, 50-cycle coils were used and the same current (mA) was supplied to them in both the a.c. and d.c. cases.

A preliminary test was taken with the magnets unexcited, and the relationship between the no-load losses and the speed was obtained.

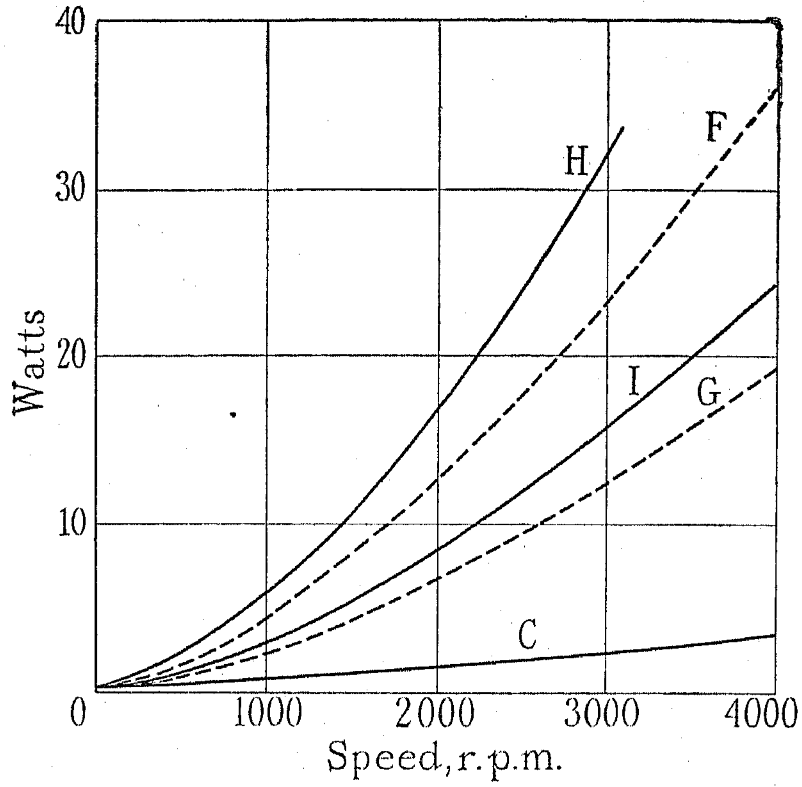


Fig. 7.—Comparison between single-phase similar and alternate polarity and d.c. similar and alternate polarity.

Curve F.—Single-phase (alternate polarity).
Curve G.—Single-phase (similar polarity).
Curve H.—Direct current (alternate polarity).
Curve I.—Direct current (similar polarity).
Curve C.—Chasing-motor no-load losses.

Four tests were then carried out, two with the coils excited by direct current and two with the coils excited by single-phase alternating current. In both cases the first test was taken with alternate poles having the same polarity and the second with all the poles having the same polarity. The results of these tests, plotting the total watt input against the speed in r.p.m., are shown by the curves in Fig. 7, where curves H and I represent the d.c. relationship and curves F and G the single-phase relationship.

These basic tests were carried out to determine first of all the general characteristics of the motor when loaded with the damping load and with the electromagnets excited in such a manner that no possible shifting or rotating of the field could be conceived.

One of the points of interest which arises in regard to these curves relates to the type of curve one would expect to obtain. If the disc had no inductance, then the relationship between the damping watt input and speed would be a square law, i.e. the damping watts would be proportional to the square of the speed and the damping torque proportional to the speed. Owing, however, to the inductance of the disc, as the speed increases the eddy currents produced by the cutting of the flux shift their axes forward in the direction of rotation. This effect is shown by the fact that these curves do not follow the square law.

Another interesting point is the comparison between the d.c. curves H and I and the a.c. curves F and G, tested under the same conditions of polarity. For instance, compare curve H with F and curve I with G, and remember that the same milliamperes were flowing in the coils, i.e. the same r.m.s. value of the flux existed in the gaps in each case. It will be observed that the a.c. damping is less than the d.c. damping in both cases, this being due to the additional reactive effect of the disc when carrying alternating current.

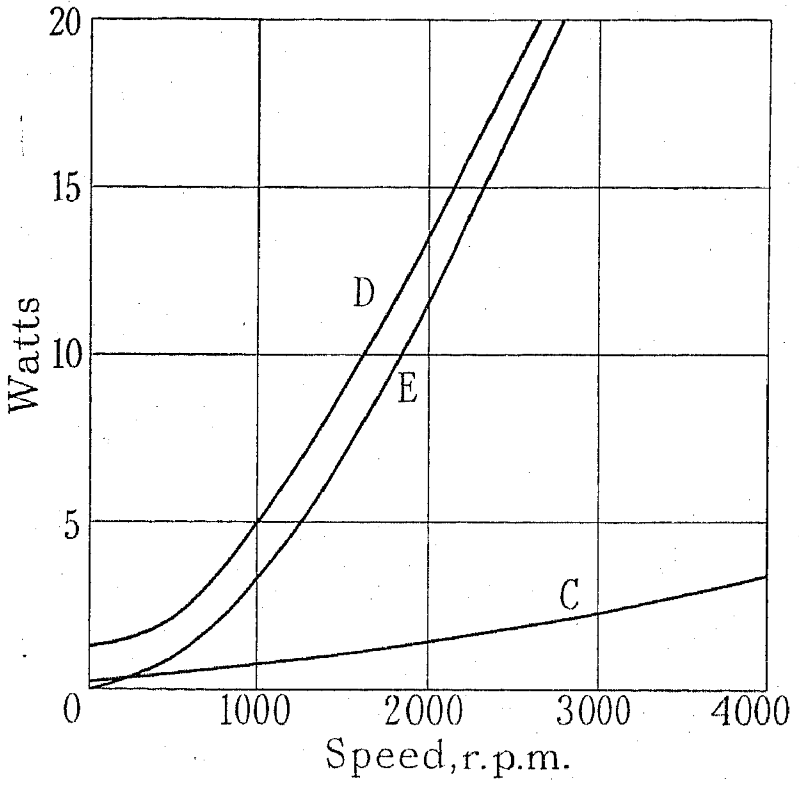


Fig. 8.—Two-phase fields.

Curve D.—Disc rotating against induction torque.
Curve E.—Disc rotating with induction torque.
Curve C.—Chasing-motor no-load losses.

As already mentioned, the six magnets formed two sets, i.e. were not equally spaced around the circumference. Each set consisted of three magnets and could be regarded as a separate electromagnetic type of meter, the two outer coils representing the current coils and the centre coil the potential coil, or vice versa. The object of this arrangement was to obtain as high a driving torque on 2-phase current as possible. I might mention that tests on 2-phase and 3-phase current with the magnets equally spaced gave less driving torque but practically the same damping torque.

Tests were then carried out on the two sets of electromagnets excited from a 2-phase supply and arranged in the following order: (i) Phase 1, Phase 2, Phase 1, (ii) Phase 2, Phase 1, Phase 2, although it was found that the result would not have been affected if each set had been arranged in the same phase order.

In all, three tests were taken, as follows:—

(1) With the outside magnets of each set having the same polarity.

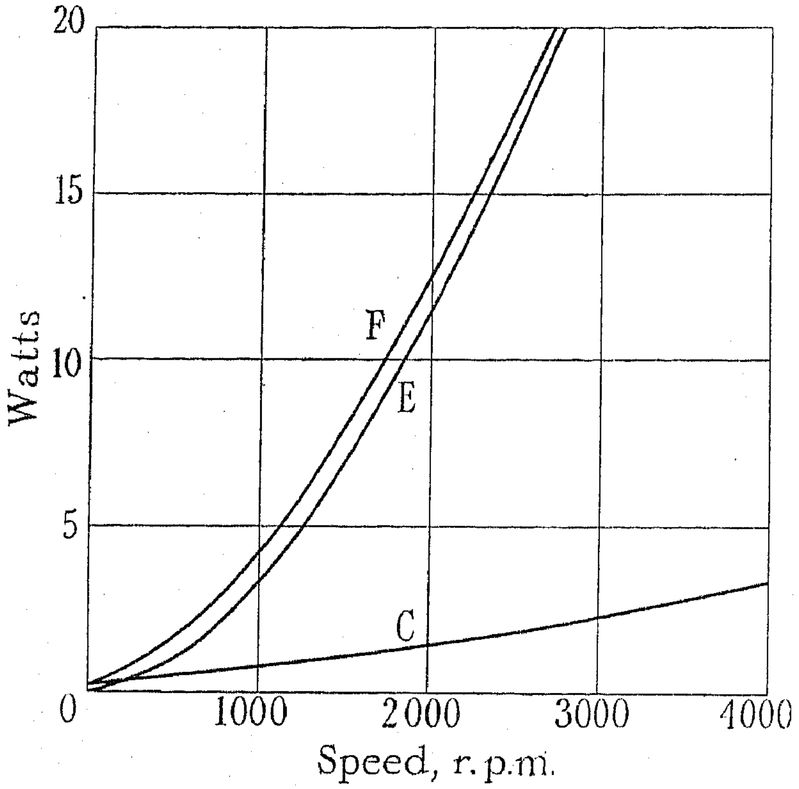


Fig. 9.—Comparison between 2-phase (disc rotating with induction torque) and single-phase (alternate magnet polarity).

Curve F.—Single-phase (alternate polarity).
Curve E.—Two-phase.
Curve C.—Chasing-motor no-load losses.

(2) With the polarity of the leading magnet of each set reversed.

(3) With the polarity of the trailing magnet of each set reversed.

No driving torque existed in the first test. In the second a torque was produced in the direction of rotation. In the third a torque was produced against the direction of rotation.

Fig. 8 shows the relation between the total watt input and speed in r.p.m. for conditions 2 and 3, where curve E represents the results for condition 2, i.e. with the induction torque in the same direction as the rotation, and curve D condition 3, i.e. with the induction torque in the reverse direction to the rotation.

I would draw attention to the fact that the no-load loss, i.e. curve C, does not strike the zero, owing to the fact that a certain amount of current has to be passed through the armature to start the motor, and consequently this appears as a small loading at " zero " speed. In regard to curve E, it will be noticed that the watts taken by the motor at starting are reduced owing to the forward induction torque existing at the disc spindle.

One of the most important points shown by these curves is that a constant difference exists between curves D and E at all speeds. It would appear, therefore, that a constant torque due to the induction element exists at all speeds taken. This constant difference would seem to prove that the induction torque cannot be due to a rotating or shifting field, as this torque would be expected to disappear at synchronous speed, i.e. 600 r.p.m. Such a constant difference would be expected from a torque produced by the transformer action previously outlined.

Fig. 9 illustrates another comparison of the similarity between the alternate-polarity single-phase test and the 2-phase test with forward induction torque. It will be seen that the curves are practically identical in shape, a constant difference due to the forward induction torque again being shown.

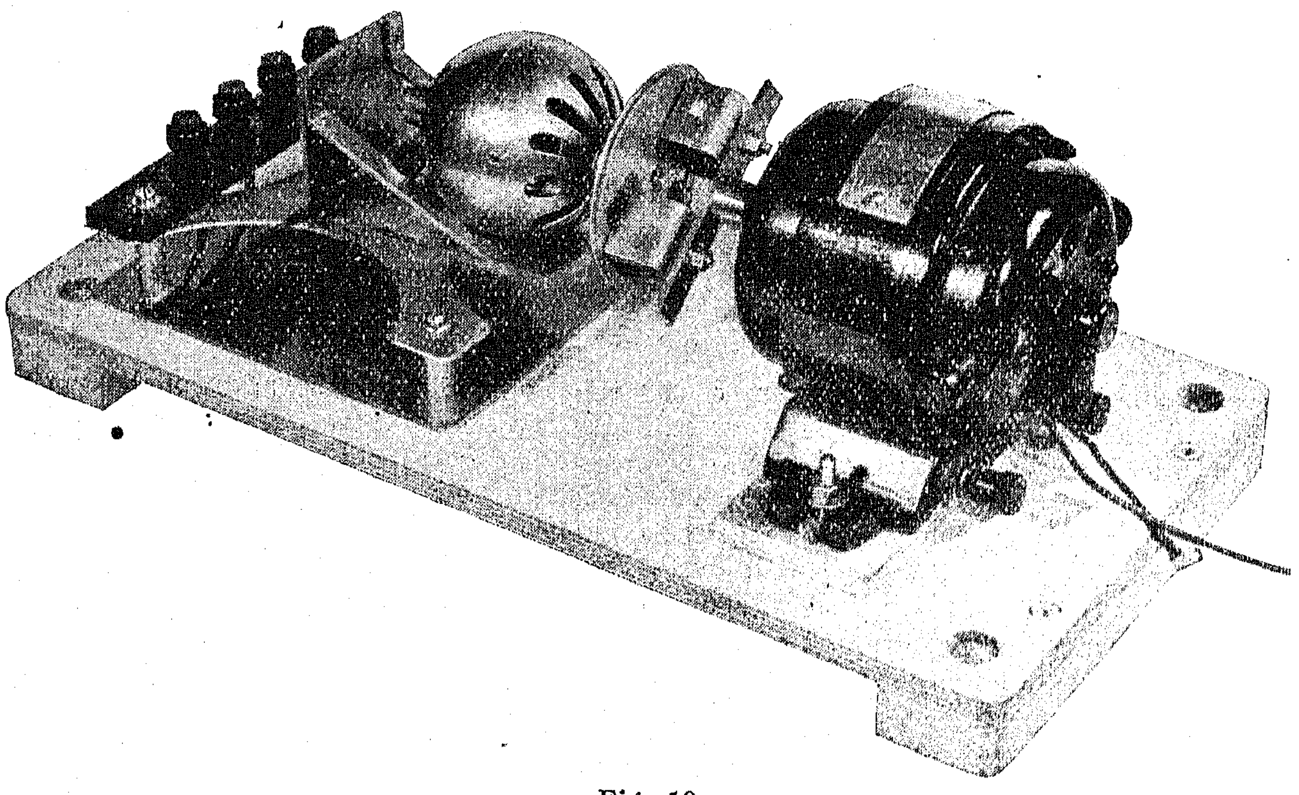


Fig. 10

Fig. 8 and Fig. 9 illustrate another very important point. Bearing in mind that the presumed synchronous speed of the model is approximately 600 r.p.m. and that if the whole field shifted or rotated the watts taken by the motor at this speed would only represent no-load losses at this speed, you will now see that these curves show that this is definitely not the case, as the total loss curve strikes the no-load loss curve considerably below what could possibly be the synchronous speed. This argument would also apply to the assumption that only a portion of the flux shifts or rotates, as the curve would be expected to drop at synchronous speed.

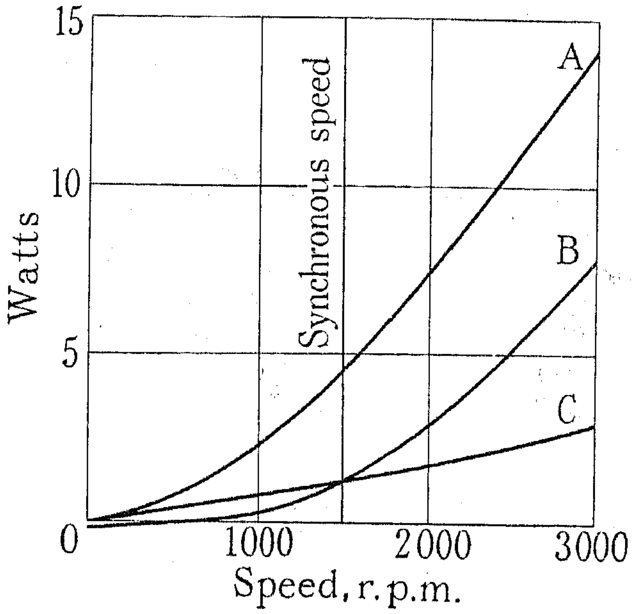


Fig. 11.—Test with true rotating field.

Curve A.—Damping and losses (magnet stationary).
Curve B.—Damping and losses (magnet rotating at 1 500 r.p.m.).
Curve C.—Chasing-motor no-load losses.

In short, the results of these tests provide in my opinion an unanswerable argument against the rotating or shifting field theory.

To complete the series, Fig. 10 shows an experiment which was carried out on a model constructed to produce a true rotating field by rotating permanent magnets by means of a d.c. motor and rotating a disc within their field with a motor similar to that used in the previous experiments.

Fig. 11 shows the results of these experiments.

Table 2

		Actual speed	Calc. syn. speed (approx.)
		r.p.m.	r.p.m.
Meter A.	Full-load watts ..	868	600
Meter A.	Twice full-load watts..	920	600
Meter B.	Full-load watts ..	510	360
Meter B.	Twice full-load watts..	680	360

Curve A plots the relationship between the total watt input and speed in r.p.m. with the permanent magnets stationary. Curve C gives the no-load loss curve, and curve B gives the total watt-input/speed curve with the permanent magnets rotated at 1 500 r.p.m. in the same direction as the disc.

These tests demonstrate two important points for comparison with the previous curves:—

(1) That curves A and B are not similar, i.e. no constant difference exists between them.
(2) That curve B strikes the no-load loss curve C at synchronous speed.

These results were to be expected and contrast sharply with results obtained from the 2-phase test.

As a matter of interest, the actual speed of two well-known makes of meters from which the permanent magnets and clocks had been removed was measured, with the results shown in Table 2.

Meter A was of the 3-pole type and meter B of the 5-pole type. I need hardly add that these results do not assist greatly in affirming the existence of a field which shifts or rotates, as the discs appear to run considerably above the calculated synchronous speed.

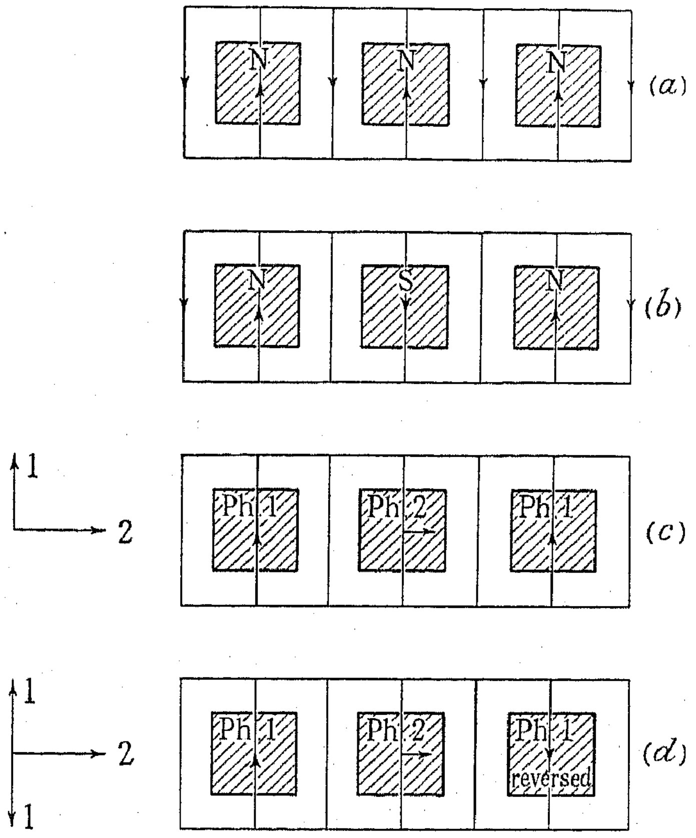


Fig. 12.—Theoretical comparison between damping torques in d.c., single-phase, and 2-phase cases.

(*a*) Single-phase and d.c. Similar poles.
(*b*) Single-phase and d.c. Alternate poles.
(*c*) Two-phase. Outers same polarity.
(*d*) Two-phase. Outers opposite polarity.

In case some of you may have wondered why variations in the damping torque for the same coil current (mA) and speed exist under the different conditions, Fig. 12 illustrates diagrammatically the various combinations used in the foregoing tests.

Now I want you to look at the problem from a different angle. It occurred to me that if it could be proved that the same driving torque could be produced by a 2-phase electromagnetic system as by direct current, when using the same amount of current in the moving element and fluxes in the electromagnets in both cases, then not only would this prove that the whole flux was required to produce the driving torque in the 2-phase or normal meter case, but would go far to explain the simplicity of the transformer theory.

Fig. 13 illustrates the apparatus constructed for this purpose. It consists of three electromagnets arranged with their poles pointing to a common centre. Pivoted to swing freely within the polar gaps is a moving coil under spring control, one end of the spring being attached to the spindle and the other to a torsion head suitably scaled. It was thus possible to measure the torque on the coil for any given position within the polar gaps, the ends of the coil being brought out to suitable terminals. To all intents and purposes this model forms an ordinary moving-coil instrument, and the moving coil may be regarded as a part of a disc.

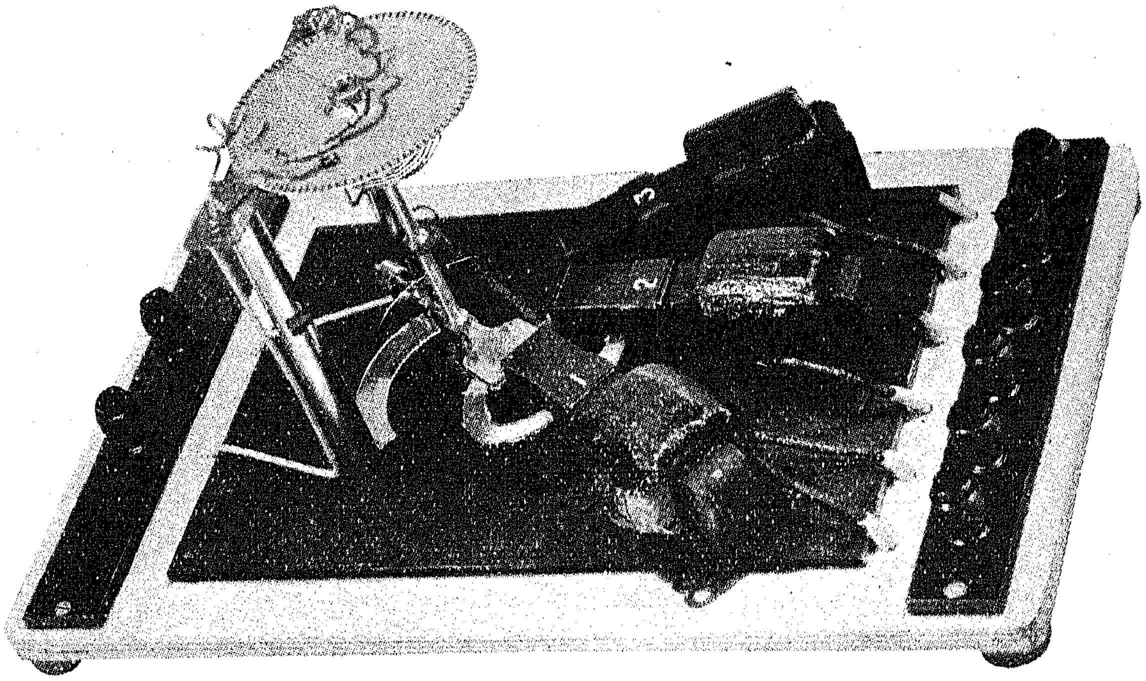
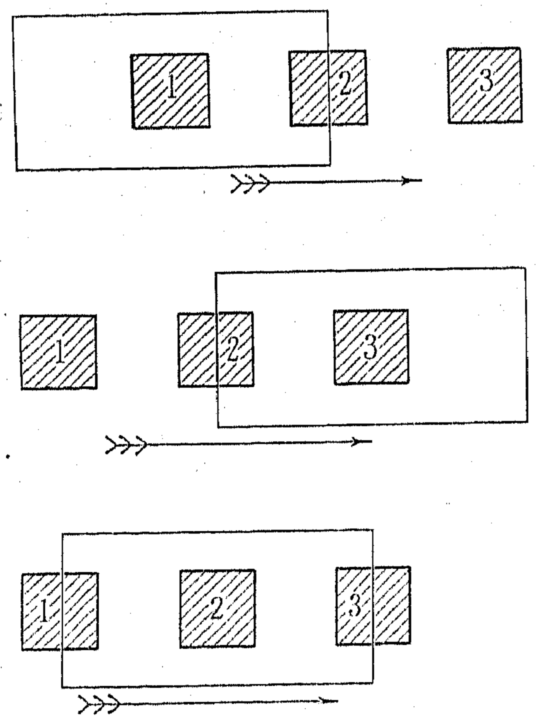


Fig. 13



Two-phase tests.

(1) No. 1 electromagnet inducing.
No. 2 electromagnet driving.

(2) No. 3 electromagnet inducing.
No. 2 electromagnet driving.

(3) No. 2 electromagnet inducing.
Nos. 1 and 3 electromagnets driving.

D.C. Tests.

No. 2 electromagnet excited.
Moving coil excited.

No. 2 electromagnet excited.
Moving coil excited.

Nos. 1 and 3 electromagnets excited.
Moving coil excited.

Fig. 14

(NOTE.—Two-phase test—Nos. 1 and 3 electromagnets on phase 1 and No. 2 electromagnet on phase 2 in quadrature.)

The first test consisted in measuring the open-circuit voltage of this coil, with each electromagnet excited by alternating current at a constant voltage in turn, and with the centre of the moving coil under that pole, a valve voltmeter being used for the purpose. At the same time the milliamperes in each electromagnetic coil were measured at this voltage. The ohmic resistance of the moving coil was then measured, and by means of these two values the approximate in-phase milliamperes which would exist in the coil were obtained. As a check, the actual milliamperes were measured on a thermo-junction milliameter, and the agreement was extremely close, showing that the power factor of the moving coil was very near unity. The following torque-measuring tests, illustrated diagrammatically in Fig. 14, were carried out.

(1) D.C. Test.

The moving coil was placed with its centre over pole 1, and the same d.c. milliamperes as in the a.c. test above were passed through coil No. 2. At the same time the equivalent current of that obtained from the preliminary a.c. test was passed through the moving coil. The torque obtained from the interaction of the conductors lying within pole No. 2 was then measured. A similar test was taken with the moving coil having its centre over pole No. 3 with coil No. 2 still excited. In the third test the moving coil had its centre over pole No. 2, with electromagnetic coils Nos. 1 and 3 excited, the current through coil No. 3 being reversed to that in coil No. 1.

The sum of the torques so obtained was equivalent to 6·35 g-cm, consisting of the following values:—

	g-cm
Test No. 1	1·5
Test No. 2	1·75
Test No. 3	3·1
Total	6·35

(2) A.C. Test.

Electromagnetic coil No. 1 was excited from phase 1 with the same milliamperes as in the d.c. case.

Electromagnetic coil No. 2 was excited from the quadrature phase with the same amount of current as in the d.c. case. Looked at from the point of view of the transformer theory, electromagnetic coil No. 1 was inducing into the moving coil and was producing no torque on it whatsoever, the torque measured being produced by the current in the moving coil acting on the flux in the gap of electromagnetic coil No. 2.

A similar test was carried out with the moving coil having its centre over coil No. 3, which was excited from phase No. 1 with reversed polarity. A third test was carried out with the moving coil over pole No. 2 and the coils were excited as follows: Coil No. 1 phase 1, coil No. 2 phase 2 in quadrature, coil No. 3 phase 1 with reversed polarity to coil No. 1.

The following torques were obtained:—

	g-cm
Test No. 1	1·5
Test No. 2	1·8
Test No. 3	3·5
Total	6·8

The difference between the a.c. and d.c. tests is approximately 6 per cent. Conditions, however, in the two tests were not absolutely identical owing to the slight difference in leakage which would occur owing to the fact that in the a.c. case not less than two coils were excited at a time, whereas in the d.c. case only one coil was excited at a time.

The results would appear to confirm that the whole flux is required to produce the driving torque in the instruments under discussion and seem to rule out definitely the assumption that only a portion of the flux shifts or rotates. At the same time the results confirm the transformer theory.

I think that it will be clear from the model and these experiments that the general fundamental theory of the induction instrument is simple. The total driving torque is the product of three terms:—

(1) The eddy currents produced by transformer action from the shunt flux, which are approximately in quadrature with this flux, produce a torque by their interaction with the in-phase flux in the two current poles, i.e. poles 1 and 3 in the model.

(2) Added to the above torque is the torque produced by the eddy current produced by transformer action by the in-phase current flux on the shunt flux, i.e. poles 1 and 2 in the model.

(3) Added to the above is a similar torque produced in a similar manner by the second current flux, i.e. pole No. 3 in the model.

As would be expected, and as shown by the experiments, the value of the first mentioned is approximately twice the value of each of the other two.

Before summing up this section of my Address I should like to describe one more experiment which illustrates the independence of the two fluxes in a meter. The model is similar in construction to that shown in Fig. 13, with the exception that a standard meter is used and an additional coil is placed in series with that mounted in the gaps, i.e. the two coils form a closed circuit, both coils having the same electrical characteristics and dimensions. This model is illustrated in Fig. 15. The experiment consists in first exciting the current and potential coils in the normal manner with the external coil in air, and measuring the driving torque with the moving coil directly under the shunt iron. The second stage of the experiment consists in switching off the shunt circuit of this meter, placing the external coil under the excited shunt coil of a second meter of similar design and characteristics, and again measuring driving torque. The driving torques are equal in both tests. Exponents of the transformer theory would of course expect this result, but it leaves the disciples of the rotating or shifting field theory with the difficulty

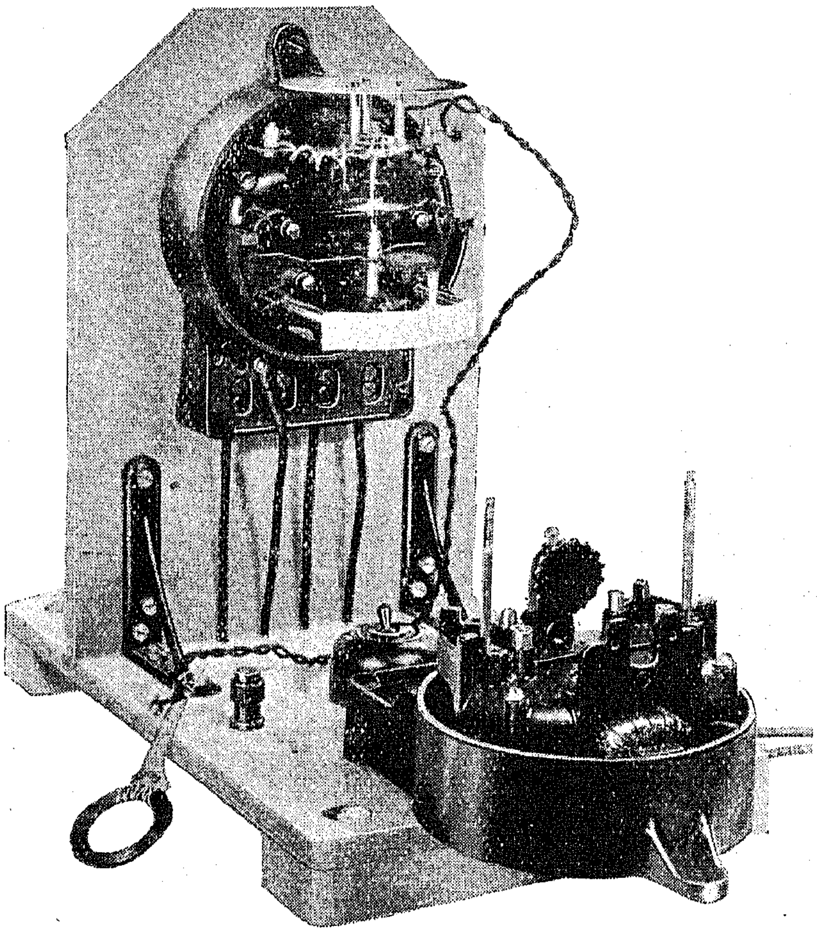


Fig. 15

of describing the phenomenal jumping powers of a 2-phase field.

To clarify the position, I will now sum up these experiments. The most important point demonstrated by them is that not a single result provides any argument or confirmation that a rotating or shifting field exists in the instruments under review, in spite of the fact that the experiments were carried out with the specific purpose of finding this rotating or shifting field, if it existed. On the other hand, all the conclusions which may be drawn from the experiments demonstrate that the transformer theory is the true explanation of the phenomena. The argument for this theory may be briefly stated as follows:—

(1) That a constant driving torque exists at all speeds up to the maximum speed taken, for a 2-phase or normal meter case.

(2) That the curves plotting the relationship between the total watt input and speed in r.p.m. for d.c. single-phase and 2-phase excitation follow the same law.

(3) The watt/speed curves for 2-phase excitation show no " dip " to the no-load loss curve at calculated synchronous speed as shown by similar curves plotted for the experiment demonstrating the true rotating field.

(4) That the discs of two standard meters with their permanent magnets and clock mechanisms removed reached speeds considerably above the calculated synchronous speed.

(5) That the driving torque produced by this type of 2-phase instrument demands all the flux produced within the polar gaps of the electromagnets.

(6) That it is difficult to explain the fact that the same torque is produced in the manner demonstrated in my last experiment with two identical meters if a rotating or shifting field is assumed to be the explanation of the phenomena.

In conclusion, I should like to express my thanks to the following: Capt. J. M. Donaldson, for his kind permission to carry out this research; my colleagues, particularly Mr. Martin, Mr. Talbot, Mr. Boyson, for their assistance in the experiments; Mr. A. Ailes for his assistance in the preparation of this Address; and finally Mr. Butherus and Mr. Hill for assistance with regard to some of the components used in the experiments.

TRANSMISSION SECTION: CHAIRMAN'S ADDRESS*

By P. DUNSHEATH, O.B.E., M.A., D.Sc., Member.

(*Address delivered* 11*th November*, 1936.)

It is my first duty in taking this chair to express my lively appreciation of the honour you have conferred upon me.

The Transmission Section, although the youngest, has already achieved the distinction of being the largest of the three Sections of The Institution. Our membership to-day is 1 653 and there is every prospect of our remaining the largest Section and, therefore, a very important factor in the success of The Institution.

I feel that the chairmanship of this Section is a position of importance and responsibility, and I shall do my utmost during my year of office to advance the interests of the Section and to uphold the tradition of our great Institution.

Members of the Transmission Section of The Institution are for the most part dependent for their food and clothing, and for the maintenance of a roof over their heads, on the correct behaviour of a very large number of very small entities known as electrons. The investigations of the forty years which have elapsed since J. J. Thomson discovered the electron have left us with the accepted fact that these tiny discrete bodies constitute the basic elements of electricity. Our business in this Section is the successful transfer of electricity from place to place, and in carrying out our function of electron shepherds it behoves us to know as much as possible about the habits of these interesting charges.

A possible title for this Address might have been " The Electron, at Work and Play," but in recalling papers published before The Institution and elsewhere I find the general view held by electrical engineers is that the electron is always at work, a willing worker to be harnessed for our use. As a cable maker I must, of course, give the electron full credit for what he does inside the conductor, although, even here, our ideas are in the process of being revolutionized by some recent experiments in the United States. It seems that if we are transmitting energy along a concentric main we need only raise the frequency sufficiently high to make it possible to withdraw the conductor from the dielectric and leave the energy streaming along inside the outer conducting tube without a return path. Going one stage further, we can apparently remove the outer conductor also, the energy continuing to travel along the rod of dielectric only. Practical energy transmission is, however, a long way behind this pioneer work, and, so far, we depend upon the useful activities of the electron in the conductor.

But even if the electron is helpful at times we cannot overlook the great amount of harm which he can do when in a playful mood outside the conductor. In such circumstances, far from being a help the electron becomes a hindrance—a veritable nuisance.

Mr. C. C. Paterson has shown† in a fascinating manner how the liberation of the electron from the conductor has had extensive industrial consequences, but in his experiments, and in the branches of electrical engineering which he represents, he and his colleagues are fortunate in being able to maintain a strict control over the free electron. They deliberately invite it to emerge from the conductor, but only under conditions laid down beforehand whereby the stream of electrons is manipulated at will to the purpose in hand. The cable maker, on the other hand, does not want the electron liberated from the conductor, and when, contrary to his intentions, such liberation does take place, the industrial consequences are usually very undesirable.

It might be held that once the electron has demonstrated its activity in a cable dielectric it is too late to do anything, and that whereas the visual effects of the free electron are helpful in a study of, say, illumination and photo-electric problems, they cannot be of much use in the study of dielectrics. This is not quite true, however; the visual study of dielectric deterioration under electrical bombardment has proved a most profitable field of research, and the progress of high-voltage cable development, which depended for many years to a great extent on theoretical deductions, was considerably accelerated when cable scientists started to take the cable to pieces after a test and examine in detail the nature of the deterioration.

We can sometimes learn more by studying visible effects than by pure theorizing, and I propose, therefore, to show this evening a few practical experiments which illustrate some of the undesirable tendencies of the electron in a cable dielectric. Although several of the experiments are already known, they have never previously been shown before this Institution, and, moreover, certain of them possess a new significance when considered in the light of our up-to-date knowledge of cable performance.

DIELECTRIC ACTION WITH BOUND ELECTRONS

The activities of an electron in a dielectric may be classified under two separate and distinct heads, one static and the other dynamic. In the first place, when a dielectric is subjected to electric stress it becomes polarized; an observable change in its electrical properties is produced, but the electron is not freed. In the second form of activity, known as ionization, the electron is actually liberated and produces effects which are explainable on the basis of the electron acting as a projectile.

In the former type of dielectric action an elastic distortion of the atom of matter appears to take place, resulting in a rearrangement between the positive nucleus and its neutralizing electrons. If the electrons are rotating around the positive nucleus then the rearrangement under stress probably consists of a stretching of the orbit in the direction of the field. In any case the result is to bring into evidence a negative charge on one face of the dielectric and a positive charge on the opposite face. The extent of the orbit distortion is related to the permittivity of the dielectric; the higher the permittivity the greater the distortion.

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* The Address was illustrated by about 20 experimental demonstrations with a specially constructed high-voltage epidiascope.

† " The Engineer and the Free Electron," *Journal I.E.E.*, 1934, vol. 75, p. 447.

Surface effects due to the action just outlined are important both within the cable dielectric and in the design of joints and terminals. They are clearly demonstrated by subjecting mixtures of fluid dielectrics to stress and observing the movement which takes place owing to the forces brought into play.

If we dip a metallic rod into the upper surface of a small quantity of insulating oil, the surface rises slightly as a meniscus due to capillary action. If we then apply a voltage between the rod and a flat electrode lying in the oil the surface rises much higher. Due to the difference in permittivity between the oil and the adjacent air, the orbit distortion in the oil is greater than in the air. In the vicinity of the dipping rod there is an equalization of the field in a vertical direction—a short-circuiting or relieving of the orbit distortion—and the result is a difference of surface conditions along the oil-air surface which brings certain forces into operation and results in a crowding of the oil towards the electrode. Equilibrium is reached when the force of gravity on the piled-up oil balances the difference in electrical force along the surface.

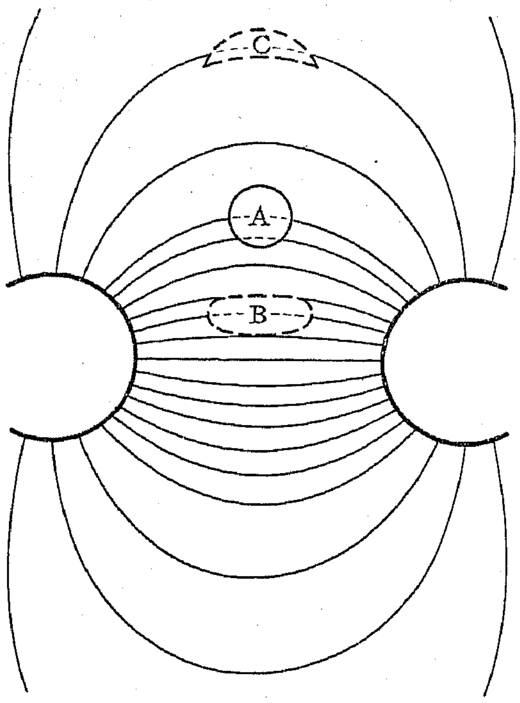

Fig. 1.—Diagram showing globules of one oil in another subjected to an electric field.

A = globule of same dielectric constant as medium.
B = globule of higher dielectric constant than medium.
C = globule of lower dielectric constant than medium.

Another illustration of the effect of bound electrons at a surface between two different liquid dielectrics is obtained by suspending globules of one in a mass of another having a different dielectric constant, and then subjecting the system to an electric stress. Two useful oils for this purpose are castor oil, with a dielectric constant of about 4·5, and transformer oil with a value of less than half this figure. The castor oil is the heavier of the two, so that globules of castor oil released in a mass of transformer oil will fall by gravity. To introduce the electrical effect we may submerge two spherical electrodes in a mass of transformer oil with a gap between them, as shown in Fig. 1.

The high-dielectric-constant castor oil is drawn into the field by an action which may be explained from energy considerations. As the energy stored in the strong part of the field is inversely proportional to the dielectric constant of the particular dielectric there, the replacement of a quantity of transformer oil by the high-dielectric-constant alternative results in a diminution of the total potential energy of the system. Globule A, therefore, if of castor oil in a medium of transformer oil, moves to position B.

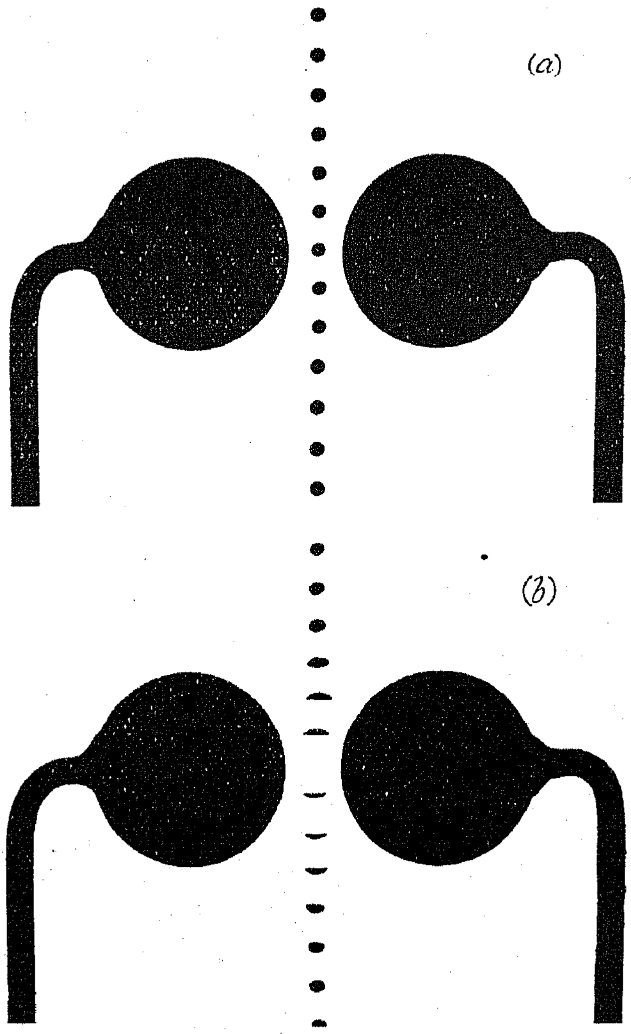

Fig. 2.—Drops of transformer oil in castor oil.

(*a*) Before application of voltage.
(*b*) After application of voltage.

From the same kind of consideration a globule A of transformer oil suspended in a mass of castor oil will be repelled from the gap to position C.

Fig. 2 illustrates globules of transformer oil in a medium of castor oil being repelled from the field produced by two spherical electrodes.

A further example of the effect of bound electrons in a mixed dielectric is obtained by bubbling air through oil in which are immersed two plate electrodes. From considerations already discussed the low-dielectric-constant air bubbles are repelled from the electric field.

ELECTRONS AND IONIZATION

The limiting condition for satisfactory operation of a cable dielectric is the voltage at which breakdown or flashover takes place, either in the liquid part of the medium or in the enclosed gas spaces known as voids. The action may be sudden or may extend over a long period of time, but in either case the electron is responsible.

The breakdown of a dielectric is due to the passage of electrons at an excessive rate, and to understand the matter, therefore, we must know the origin of the electrons and what are the factors which cause them to travel.

All commercial liquid and gaseous dielectrics exhibit the phenomenon of ionization to a small degree, that is they contain charged particles or carriers of negative electricity and the application of a voltage results in a flow of current. In a liquid dielectric, such as insulating oil or compound, the electrons are released by the process of solution, and the magnitude of the ionization is a function of the purity and dryness of the oil. It is, of course, very small. In a gas, however, the ionization, although it may be produced by such external causes as radiation from radium, ultra-violet light, etc., is usually the consequence of collision between rapidly moving electrons speeded up by the electric field and molecules of the gas. The number of charges in a gas, even under the most intense ionizing agent, is only a very small fraction of those present in a dilute electrolytic solution, but under the influence of a high voltage may assume such proportions as to cause destruction of the surrounding dielectric material.

THE ELECTRON AND THERMAL FAILURE

The limitations of cable performance imposed by the electron in the liquid component of the dielectric lie in the effect of the ionization on the conductivity and dielectric loss.

When moisture and impurities are present the electrolytic ionization produces high conductivity—usually expressed as low insulation resistance—and, if the value is excessive at one local spot, heating accompanies the increase in the leakage current and the cable fails.

In cables to operate at ordinary voltages it is not usually difficult to meet all the conditions necessary to ensure the avoidance of excessive electrolytic ionization. In general it simply means using pure dry materials.

In cables to operate at the very high voltages of 66 kV and upwards, however, the case is rather different. During recent years it has been established that at these voltages, even with normal attempts at avoiding electrolytic ionization, breakdown may result from thermal instability due to dielectric-loss heating, and Dr. Brazier examined the question in detail in a paper read before this Section last session.*

The absolute breakdown strength of a dielectric naturally deteriorates with temperature-rise. The dielectric loss may also increase with temperature-rise, but fortunately so also does the rate of dissipation of the heat and a balance may be maintained. On the other hand, it may happen that in a cable dielectric the loss may be very high or may increase at an excessive rate with temperature-rise, or again the external circumstances may be such as to prevent adequate heat dissipation. In any of these circumstances the temperature of the dielectric may rise to such a value as to bring the breakdown strength down to the region of the voltage applied, and failure will result.

The values of power factor obtained by the maintenance of the usual standards of purity in modern materials and methods employed in high-voltage cable manufacture ensure freedom from thermal instability on cables to work at voltages up to and exceeding, say, 66 kV, but for cables to operate at 132 kV the question assumes great importance and special care has to be taken to keep down the power factor and dielectric loss to a safe value. The connection between the possible final breakdown of the cable and the originating cause in the electrolytic movement of the electron is thus very definitely established.

The appearance of the cable after an electro-thermal failure of the type described is quite characteristic. There is a clean hole through the different layers of paper, and the only alteration in the nature of either paper or compound at points away from the puncture, but in the near vicinity of the breakdown, is a slight discoloration due to the heating. As will be seen later, this is very different from other types of failure for which the electron is responsible in quite a different way.

GASEOUS IONIZATION

We have seen that ionization in the liquid component of a dielectric does not become serious from a practical point of view until we reach the very highest voltages. The case with gaseous ionization is very different, however. The difficulties which called a halt to super-tension cable development 10 years ago, and which were overcome by the Höchstädter screen, were due to gaseous ionization of gases in void spaces within the mass of the dielectric.

What happens in a cable dielectric void is not very completely understood, but from what we do know it appears that we might reasonably draw the following conclusions. The nature of the discharge may be either (*a*) a glow, or (*b*) a spark. The accompanying effects may be either

(i) Mechanical displacement of the oil component, or
(ii) Chemical deterioration of the oil and paper components.

The influence of the phenomenon known as the electric wind is well known. Air molecules, near a point electrode producing a high stress, become ionized and are violently repelled. The extent to which the effect can influence an oil dielectric can be demonstrated by a simple experiment. If we suspend a needle electrode over the surface of a shallow bath of oil in which a lower flat-plate electrode is submerged, and apply a voltage between the two electrodes, we obtain first of all a cratering effect, followed, as the voltage is raised, by a forcing of the air into the body of the oil and the production of an emulsion.

In order to produce an emulsion of air in oil it is not necessary to employ such artificial conditions as in the needle electrode experiment. If a bubble of air exists within a mass of insulating oil the application of a sufficiently high stress will disperse the air into the body of the oil.

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* *Journal I.E.E.*, 1935, vol. 77, p. 104.

The effect originates in a mechanical disturbance at the surface between the air and oil caused by the field distortion due to the different dielectric constants, in a manner similar to some of the experiments shown earlier. A secondary action is the taking up of the finely divided air into solution. This phenomenon has been known for some years in connection with the employment of oil-filled cables, where the continued application of a voltage has improved the electrical characteristics by eliminating unwanted gas bubbles.

A further phenomenon illustrating movement of oil under electric stress has no doubt been noticed by many experimenters. When a flat-ended cylindrical electrode stands on an oily surface above a lower flat electrode the application of voltage between the two results in a violent dispersion of the oil in an irregular manner.

A very practical application of the effect is, of course, to be found in the treatment of cable-ends. If the lead is just left cut off square, the electron becomes a real nuisance in the way in which it first of all clears away the loose oil on the surface of the core papers, and then launches an attack on the substance of the papers themselves (see Fig. 3 on Plate).

COMPOUND DETERIORATION BY IONIZATION OF VOIDS

When compound is allowed to drain from a high-voltage impregnated-paper cable or migrates through repeated heating and cooling of the dielectric, void spaces are formed between the papers. Subsequent application of a voltage of sufficiently high value may result in a glow discharge in the space, and it is found that when such a discharge takes place the adjacent impregnating compound is subjected to intense chemical modification. The electron has converted the thick fluid compound in such spaces into flakes of a yellowish brown wax. This wax, a sample of which is shown in Fig. 4 (see Plate) and which is completely inactive, does not appear to be a bad dielectric in any way, and many high-voltage cables have given good performance over many years while containing large quantities of the wax. It may be that the gas generated at the same time as the wax results in a raising of the internal pressure and the production of compensating conditions. The discharge will, of course, die out as the gas pressure rises. This seems to be a popular expedient to-day to defeat the electron. Many inventors are devising gas-pressure cables in which the maintenance of gas under pressure prevents gaseous discharge even if voids exist within the dielectric.

During the past few years a useful technique known as the " magenta " test has been developed extensively by Dr. Robinson for the examination of waxing conditions in a cable. The strips of paper from the cable, after subjection to the voltage run, are unlapped one by one and immersed in a solvent which removes the unaffected impregnating compound, leaving the patches of wax undisturbed. The papers are then dried and stained with magenta dye which colours the unwaxed portions, leaving the waxed portion easily distinguishable. The pattern of the waxed portion gives a clue to the form of the void. A flat patch is, for instance, due to a separation of papers radially, while a long line of wax indicates a separation between two strips of paper on an adjacent layer.

LICHTENBERG FIGURES

In order to lead up to the most serious of the various effects of stray electrons in a cable dielectric—that of tree burning—I should like to refer to an allied phenomenon of considerable electrical interest. Lichtenberg figures have been known for 150 years. At first they were a scientific curiosity, but as our knowledge of the constitution of electricity has progressed so also has our understanding of these beautiful and remarkable patterns improved.

When a rod-shaped or pointed electrode stands vertically on a plate of insulating material lying on a lower flat electrode, the sudden application of a sufficiently high voltage between the two electrodes produces a shower of electrons over the surface of the insulating material. The effect occupies such a short period of time that it cannot be followed by the eye. It is, however, possible to make a permanent visual record in one of two ways, either by the insertion of a photographic plate or by dusting certain powders on the upper surface of the sheet of insulating material. The powders are redistributed in patterns characteristic of the particular discharges, and development of the photographic plate brings to light the same design.

There is a characteristic difference between the forms of the Lichtenberg figures from negative and positive electrodes. The negative figure (Fig. 5, see Plate) is an almost complete circular disc with dark radial lines and with the pattern occupying most of the area. This figure gives the impression that the disturbance is travelling outwards from the centre.

The positive figure, on the other hand, consists (see Fig. 6 on Plate) of a large number of tenuous streamers, very fine in their outer extremities and thickening up towards the centre. These streamers appear to be collecting from the outer darkness and gathering up to the centre.

The disturbance is evidently due, once more, to our friend the electron.

In addition to pure positive and negative figures we may obtain what have been called " slip figures " (see Figs. 7 and 8 on Plate). These appear to be due to the formation, at points remote from the electrode, of secondary centres where the electrons are collected or distributed.

These photographs of Lichtenberg figures are some of the finest that have ever been produced and I am very much indebted to Mr. L. N. Bramley who made them and who is assisting me this evening.

The definite connection between Lichtenberg figures and the electron was illustrated by Magnusson, who produced the figures for the first time under the influence of a magnetic field. By passing a sufficiently strong field through the plate on which the figures were formed, he was able to convert the straight radial into curved lines. In the negative figure he showed that passing a magnetic field from a N pole down through the plate produced a clockwise bending of the rays. A stream of electrons moving from the negative electrode at high velocity acts

Plate

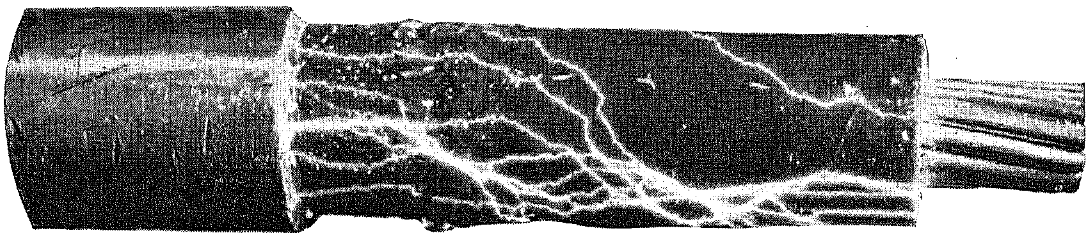

Fig. 3.—Cable end with migrating compound and flashover discharge.

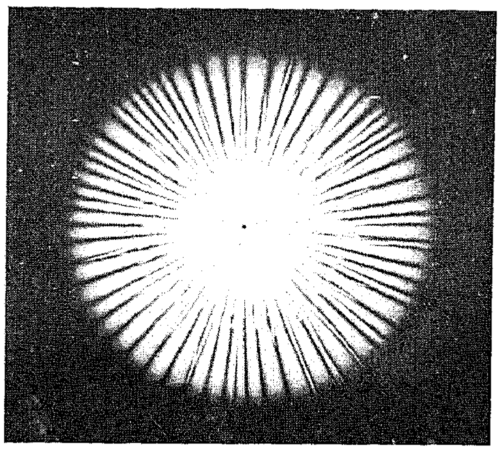

Fig. 5.—Negative Lichtenberg figure.

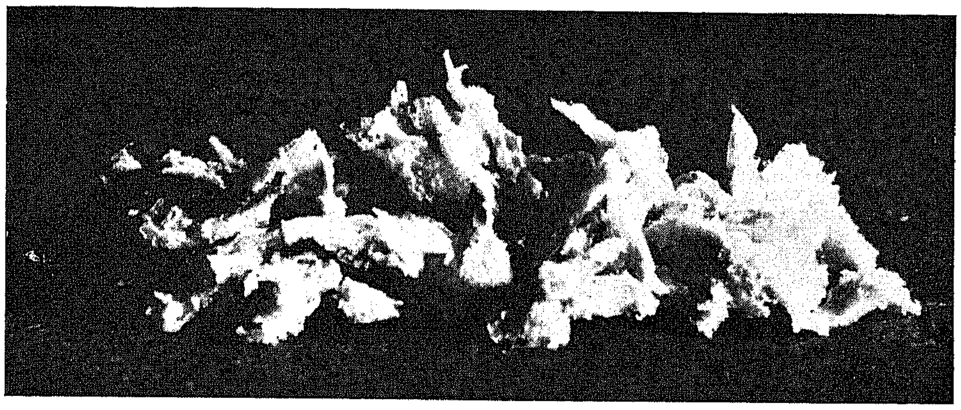

Fig. 4.—A pile of actual cable wax.

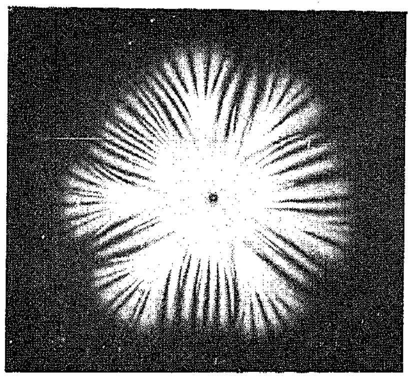

Fig. 7.—Lichtenberg slip figure, negative.

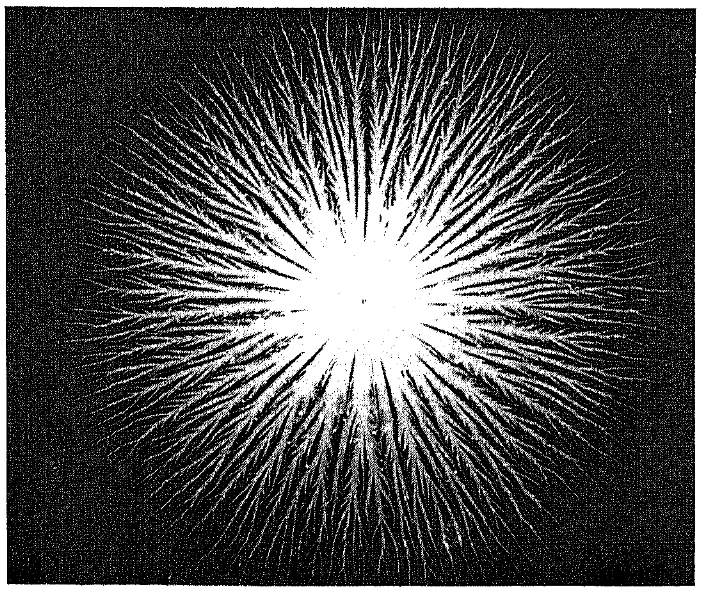

Fig. 6.—Positive Lichtenberg figure.

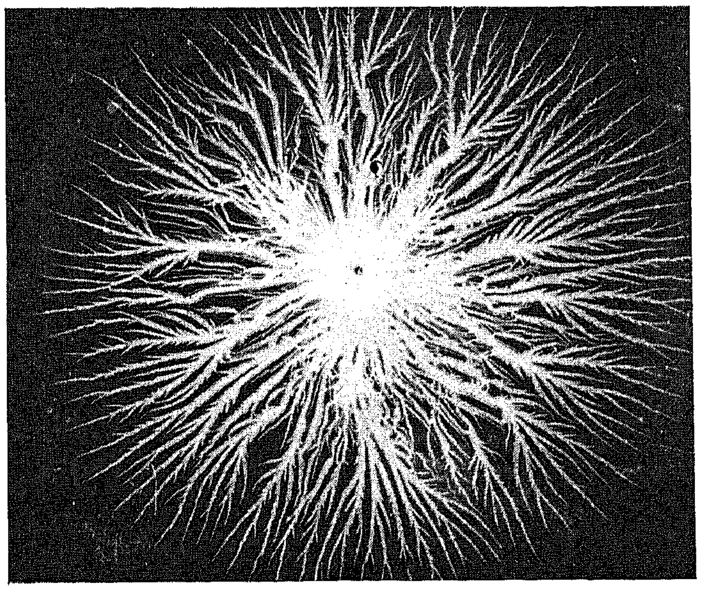

Fig. 8.—Lichtenberg slip figure, positive.

(*Facing page* 24.)

as a current and should be deflected in the clockwise direction. There have been various theories to explain the positive figure, but the most probable view is that the basis lies in a stream of electrons falling into the electrode radially from outside. The general conclusion is that electrons are primarily the active elements in the kindling mechanism in spark discharge, and that the initial step lies in the formation of Lichtenberg figures, the spark developing from the tips of the streamers. In the negative figures the electrons are projected at high velocity radially, and they also repel one another mutually. Near the positive electrode, however, secondary ionization enters into the action as the velocity of the incoming electrons increases.

The greatest interest during modern times in the Lichtenberg figures has been the practical application in the klydonograph, an instrument for recording surges on transmission systems. In this instrument a vertical rod electrode stands on the sensitive face of a moving photographic film, which is slowly drawn over a flat sheet electrode. The discharge from the rod when a sudden difference of potential is applied between the two electrodes affects the photographic emulsion in such a way as to produce the typical Lichtenberg figures on development.

As has been shown by several investigators, and in this Institution not long ago by Messrs. Melsom, Arman, and Bibby,* the characteristic of a Lichtenberg figure may be employed to give quite a lot of information about a line surge. The time of an occurrence can be recorded, the size of the figure gives a measure of the magnitude of the surge to within about 10 per cent, and, further, it is clear from what has been demonstrated above that the polarity of the surge is indicated by the shape of the figure.

DETERIORATION BY TRACKING

We have already seen that a flat void in a paper cable dielectric may become the seat of a discharge, but, so long as the discharge does not get beyond the glow stage, cheese or wax is formed apparently without any serious threat to the life of the cable. When the discharge, owing either to increase in the value of the voltage or to the shape of the void, turns into a spark, then destruction of the dielectric by carbonization sets in, and once this phenomenon has started at a point it tends to spread in the form of a treelike track.

It is usual, in the case of a high-voltage cable failure, to find a considerable amount of tree tracking, and it is this phenomenon which explains time/voltage effects and the fact that a cable may fail after months of service. The electron here may be working towards the destruction of the cable for quite a long time before striking the final blow. The mechanism may be summarized by saying that tracking starts through heavy concentrated spark discharge in a radial void, and the carbonized material carries the conductor potential outwards with a cumulative effect. Owing to the laminated nature of the dielectric the path is a diagonal one and usually travels in both directions along the cable from the originating discharge.

By unwinding a number of papers from a cable which has developed tree tracking, we can see how the discharge tracks have been formed. The detailed shapes of the carbon tracks assumed by the tree-tracking in a cable can be clearly seen in samples which have been cleaned and stained by the magenta method.

It is interesting to note that complete failure of a cable due to tree tracking is not delayed until the tracking reaches all the way through the dielectric. After a certain stage has been reached the heat generated in the tracking raises the temperature of the remainder of the dielectric thickness, which thus fails by direct puncture. This action was commonly noticed in the failure of 3-core belted cable so frequent a few years ago. Deterioration set in from the outside of the core, resulting in extensive damage to the outer papers, and this was followed subsequently by a clear puncture through to the core.

In conclusion may I say that the phenomena described and the experiments carried out are not intended as a reasoned argument leading to some new and definite theory or conclusion. They are collected together in the hope that they may prove interesting and may further stimulate thought on some of the very important activities of the electron in circumstances where its correct control may lead us a long way in the improvement of electrical transmission.

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* "Surge Investigations on Overhead Lines and Cable Systems," *Journal I.E.E.*, 1930, vol. 68, p. 1476.

WESTERN CENTRE: CHAIRMAN'S ADDRESS

By J. W. SPARK, Member.

"THE LEGISLATURE AND THE ELECTRICITY SUPPLY INDUSTRY"

(*Address delivered at* BATH, 12*th October*, 1936.)

The subject of this Address will be on the lines which I think you will expect from one whose activities are confined to the supply section of the industry. I had sought to depart from this natural tendency, but as so much attention continues to be given to the electricity supply industry by the legislature, and as the recent publication of the " Report of the Committee on Electricity Distribution " indicates a complete change in the administration of this public service, I decided to address you on these lines.

Much has already been published in the *Journal* setting out the views of members on the merits and demerits of the Act of 1926, but I hope that, now we have experience of operation under the latest legislation, my remarks may be of interest. I will deal with the subject as it affects local-authority-owned undertakings in particular.

Industries throughout the country, and particularly those of public utility, are becoming more and more subject to parliamentary control, and the effect of such control is probably more evidenced in the electricity supply industry than in any of the others.

The powers and obligations of authorized undertakers are contained in a series of Acts, Orders, and Regulations, dating from 1882, and additional Orders and Regulations are issued at frequent intervals. The true interpretation of some of the statutes appears to be still in doubt. The various Acts have not been consolidated, but some measure of co-ordination has been effected and the Ministry of Transport and the Electricity Commissioners now exercise a considerable degree of central control.

A brief review of the salient points in the Acts affecting development is desirable to indicate the trend of the legislature.

The Act of 1882

This authorized the granting of Provisional Orders and Licences by the Board of Trade. These Orders and Licences, while imposing upon the grantees certain compulsory works in the nature of providing distributing mains in scheduled streets, strictly defined the area of supply, and objections to proposals to provide supplies to premises immediately outside the statutory area—whether within the area of another authorized undertaker or not—were maintained by interests even outside the industry, so that the provisions of the Act made it in effect impossible for many premises to obtain supplies under any circumstances. Local-authority undertakers were required to submit specific schemes for all extensions to their undertakings; these schemes were subject to public inquiry, and even extensions to the distributing network were delayed for considerable periods. These restrictions obtained up to the passing of the Act of 1919. Section 27 of the 1882 Act is significant, although it has since been modified. It provided for the purchase of company undertakings by the local authority. The legislature indicated early in the history of the industry that public ownership was contemplated.

The Acts of 1888, 1890, and 1902

These provided little affecting development except to increase the period of tenure of company undertakers from 21 to 42 years before local authorities could exercise their option to purchase the undertakings. Provision was, however, made for the granting of powers authorizing more than one undertaker to supply electricity in one area under certain circumstances. Competition between undertakers was thus permitted.

The Act of 1888 made necessary the consent of the local authority to the granting of a provisional order for any person or company to supply electricity within its area. A form of public control was recognized.

The Act of 1909

This provided for the erection by authorized undertakers of generating stations outside the area of supply. It authorized bulk supplies and removed restrictions prohibiting the supply to specified premises outside the statutory area by providing for agreement between adjoining undertakers and made provision enabling the supply to be given even in the event of failure to agree.

The Act also made provision for the establishment of Joint Boards and contemplated adjoining local authorities combining their undertakings in a form of partnership.

It is worthy to note that the Joint Boards were to comprise local authority undertakers. Company undertakers were not included. Competition from non-statutory sources was prohibited.

The Act of 1919 and the Amending Act of 1922

These were the outcome of reports and recommendations of three committees appointed during the war. The outstanding provision in the Act of 1919 was the establishment of the Electricity Commissioners. This body was endued with certain powers, and considerable impetus has been given to proposals for development involving, in particular, works of a capital nature. It is the opinion of many responsible for the administration of electricity supply undertakings that these powers were too limited, and it is probable that much of the subsequent legislation would have been avoided had the Electricity Commissioners been vested with wider powers.

The Act made possible the setting-up of Joint Electricity Authorities to co-ordinate the generation and distribution of electricity on a regional basis. Provision was made for obtaining wayleaves, and considerable freedom and encouragement for development was provided.

The provisions of the Act in the essential features were, however, mostly permissive, Parliament having removed the compulsory powers necessary to carry out the intentions set out in the draft. It is probable that the Act of 1926 which followed would not have been promoted if Parliament had not made the alterations. The draft provided for the Electricity Commissioners to establish "electricity districts," and required local authority and company undertakers to prepare and submit schemes for the improvement of the supply of electricity in the defined district, and, in the event of failure to produce a satisfactory scheme, the Electricity Commissioners were themselves to formulate the scheme.

It is obvious that the Act failed to achieve its object.

The Acts of 1926 and 1935

It may be taken that the failure to achieve the progress anticipated under the Acts of 1919 and 1922 resulted in the passing of the Act of 1926, supplemented by the Act of 1935. The provisions of these Acts are again based upon the recommendations of a special committee appointed by Parliament, and the scheme produced, as required by the Act of 1926, has subjected the generation side of the industry to almost complete central control by the State through the Central Electricity Board.

The merits of the revolutionary nature of some of the provisions are considered by many members to be debatable, but I believe it is accepted by all responsible persons affected that co-operation has been achieved, and that there is true endeavour to make effective the intentions of the Act.

The Acts impose upon undertakers a complete change in methods for dealing with generation, but the provisions are not so comprehensive as those contained in the original draft of the Act of 1919, in that they deal almost exclusively with generation whereas the latter provided for both generation and distribution.

OPERATIONS UNDER DIRECTIONS OF THE BOARD

The authorized undertakers in six of the areas in which the Central Electricity Board operates have now experienced trading with the Board, and the owners of selected stations have experienced operation under the directions of the Board.

The tentative scheme in the Weir Report which led up to the 1926 Act contemplated the concentration of generation in 58 selected stations, but the schemes produced by the Electricity Commissioners, and the modifications, provided for 126 selected stations up to March, 1935.

The Central Electricity Board's report discloses that, during the year 1935, 148 generating stations were in operation under the directions of the Board in these 6 areas, some 25 of which were non-selected stations working under arrangements made with the owners, and that only 28 of the stations were in operation for three shifts during the whole year.

Diverse problems, of course, arise and the Central Electricity Board has put to full use its resources for solving the technical difficulties encountered.

There is, however, a problem of another class—that of the economic use of employees in stations running less than three shifts, and especially seasonally-operated stations. The problem I refer to concerns 80 per cent of the stations operating. Section 7 requires the owners of a selected station to operate the station as to output and running hours as the Board may direct, with due regard to efficiency and economy. This direction, it would appear, could be given in advance to the engineer responsible for the efficient and economical running of the station, but practical application of the section shows that this is inexpedient as, although a weekly operating programme is provided, it is materially departed from as the requirements of the area demand. Direction is therefore delegated to the control room of the Board, and the shift charge engineer in the selected station gives effect to the direction.

The Board's requirement as to output is obviously of first importance, and to meet the varying requirements in a 1- or 2-shift station the fuel standing-losses are materially increased during the running hours and greatly increased during the period the generating plant is shut down while the station is in commission. The efficiency of these stations is obviously lowered, whilst the operating staffs inevitably lose to a considerable degree the competitive interest in cost of production which prevailed under independent operation, and this is not helped by the atmosphere of menace to continued employment in which they operate.

The sacrifice of efficiency in these stations has no doubt been anticipated and may be more than compensated for by the higher efficiency of the base-load stations under high-load-factor conditions, but there remains the problem of the economic employment of the operating staff during shut-down periods and of obtaining suitable staff and labour to operate the station with due regard to the efficiency and economy if the service periods were broken.

TRADING WITH THE BOARD

There is probably no subject which has been so much discussed during two decades as selling tariffs. Those of us responsible for administration have each in our own way satisfied ourselves that we have produced tariffs which apply to the different classes of load, at rates which approximate to the varying costs of providing the supplies, but it must be admitted that in many cases the costs and tariff have not been quite closely related and that the tariffs produced have to some extent been influenced by policy and expediency. The justification for this confession may be that the market will not stand the same margin for each class of load catered for. And is not this a ruling factor in commerce? Be that as it may, it must be admitted that there is ground for public criticism of the variety of methods and rates of charge.

There are some 640 authorized undertakings catering for the public and offering probably quite this number of prices.

The Electricity Commissioners have attempted to bring about some uniformity and have succeeded only so so far as to appoint committees, representative of the industry, to consider and report.

A report and recommendations was issued in 1930, and the criticism published indicated that nearly every undertaker's tariff was the correct solution. It would in any case have been difficult, without some form of compulsion, to make a violent change, as undertakers generally were morally committed to their tariff policy and any increase in actual price to any class of consumer would have caused considerable criticism, not easy to defend.

There is indication in the " Report of the Committee on Electricity Distribution " that this position will not be maintained indefinitely. The Terms of Reference to this committee were: " To bring under review the organization of the distribution of electricity in Great Britain, including the control of statutory electricity companies by other companies, to advise on methods by which improvements can be effected with a view to ensuring and expediting the standardization of systems, pressures and methods of charge, further extending facilities (including supplies in rural areas) and reducing costs, and to make recommendations."

Amongst the comprehensive recommendations made in the report, reference is made to tariffs in paragraph 475 (1) which reads: " Standardization of Methods of Charge." Amalgamation of undertakings into a smaller number of larger undertakings will be an important step towards standardization of methods of charge and more uniform prices.

Authorized undertakers' tariffs, whatever the amended form may be, must, however, be definitely influenced by the prices paid to the Central Electricity Board for their individual supplies. These prices are imposed upon the industry in accordance with Sections 7 (4), 11, 12, and 13, of the 1926 Act, and under Sections 1 and 2 of the 1935 Act.

Section 7 of the 1926 Act defines the prices to the owners of selected stations on terms known as " adjusted station costs," that is the cost of production at that station adjusted according to the load factor and power factor of that part of the supply taken by the owner, plus a proper proportion of the Board's expenses. The price when ascertained applies only to so much of the supply taken as is generated at the owner's station, and the balance is chargeable at grid tariff.

It is obvious that such a tariff will produce a large range of prices to the various undertakers to which it applies and that it can vary from year to year according to the use made of the station by the Board. The Act, however, provides under Section 13 that the owner shall not pay to the Board, for the whole of the supply taken, more than the cost that would have been incurred by the owner under independent operation.

Experience in operating under the scheme has shown that Section 7 is of little practicable value and that most of the selected station owners have fallen back on Section 13.

Section 13 also produces a range of prices and brings into consideration both estimates and hypothetical considerations. The section provides that if the owner of a selected station proves to the satisfaction of the Electricity Commissioners that the cost of taking the supply in any year on the terms provided by the Act exceeds the cost of independent operation the price to be paid shall be adjusted accordingly. This necessitates the preparation and proof of the following estimates:—

(1) The additional plant, if any, that would have been necessary for independent operation.
(2) The proportion of any additional plant installed by arrangement with the Board that would have been necessary for the undertaker's purposes only.
(3) Cost of hypothetical plant.
(4) Efficiency of the generating station under the condition of the hypothetical extension.
(5) Whether a complete new generating station would have been necessary, and the cost of production at the hypothetical station.

It will be obvious that each of these estimates is liable to dispute between the Board and the undertaker, and that the ultimate decision of the Commissioners must leave the price to be paid by the various owners of selected stations for their supplies in approximately the same relative position as their costs of production before the provisions of the Act were put into effect.

Section 11 has produced the " grid tariff " and applies to authorized undertakers who are unprotected in respect of the price to be paid for the whole or part of their supplies by other sections of the Act. The grid tariff also produces a series of prices. The fixed kW charge with variations may be practically the same for all areas except one which enjoys a lower rate, but the method of application is governed, not by the amount of trading with the Board in any one year but by the undertaker's maximum demand in the year 1932 under independent operation. The anomalous position arises that undertakers in the same area making the same maximum demand on the Board pay different prices in respect of this part of the tariff. The running charge varies in different areas. Undertakers in the different areas pay different unit rates; there are five rates on basic costs of fuel, and three rates for varying the basic prices per unit according to variation in the price of fuel.

Section 12 produces an even greater variety in prices. This section provides that where an authorized undertaker gives a supply in bulk to another authorized undertaker or for certain purposes to a railway company, whichever of the multitudinous prices the first undertaker is required to pay to the Board, the price charged shall be on the same terms with the addition of such charges and allowances in respect of the transmission line used to provide the bulk supply as are set out in the Third Schedule. If the undertaker taking a bulk supply from the owner of a selected station has contracted for the supply after the date of the passing of the Act the price to be paid may be considerably more or considerably less than even the contracted price or grid tariff, and should it be necessary to take additional supplies from the grid at another point in the area that part of the supply is chargeable at grid tariff. There are cases of authorized undertakers taking bulk supplies at different points in their area of supply, paying different prices for similar supplies.

Section 1 *of the Act of* 1935 provides another series of prices. The section applies to the owners of non-selected stations operating by arrangement with the Board.

Section 2 amends section 11 of the 1926 Act and makes clear that yet another series of prices may be applied to obtain consumers " whose needs are of an exceptional nature."

It is my submission that the prices produced by these Acts have a greater variety than the tariff prices of the offending undertakers and have less uniformity than any undertaker's method of charge.

Whatever justification there may be for the variation in prices imposed by statute, applies equally to the tariffs of authorized undertakers.

The provisions of the Acts of 1926 and 1935 can only perpetuate the lack of uniformity of charges made to consumers, and it is difficult to reconcile this position with the Terms of Reference to the Committee appointed by the legislature to cure an evil to which it contributes, and makes no reference to the inconsistencies of the prices imposed upon undertakers whose tariffs are the subject of vituperation.

In addition, the legislature has appointed a committee " to advise on methods by which improvements can be effected with a view to ensuring and expediting the standardization of systems, pressure, and methods of charge " by undertakers.

That there is confusion in the supply industry is common knowledge amongst undertakers. Reference to the Central Electricity Board's published accounts and to the accounts of many other authorized undertakers discloses that there is disagreement as to the operation of the sections of the Acts dealing with payment to and from the Board. The task of the Board's staff in this respect is not enviable.

This may be a passing phase, but as proof of cost in any year under hypothetical conditions is required of undertakers the prospect of settlements within a reasonable time appears to be remote and the true financial position of the parties affected is left in a state of uncertainty.

One obvious step to ensure the standardization of method of charge is an amendment to the Act of 1926 to establish one tariff for each area. It is appreciated that such a tariff must give to authorized undertakers a rate which would not exceed the cost of production of the most efficient station in each area based upon independent operation and that this would increase the accumulated losses of the Board during the 10 years' period allowed by Parliament, but is not the provision of the Act in this respect a matter of degree?

DISTRIBUTION

Undertakers have some experience of operation under " direction "—almost complete State direction—in everything appertaining to generation, and it is apparent that " direction " is to be given in regard to distribution. The appointment of a committee to report on electricity distribution has been expected and, although we can but speculate as to how far Parliament will adopt the recommendations of the committee, there can be no doubt that legislation will be introduced to deal with this section of the industry; and it is submitted that the step taken confirms the view, often expressed, that the promises held out by politicians with the passing of the Act of 1926 cannot be achieved by measures affecting only the more efficient section of the supply industry. Distribution cannot be regarded as ancillary to generation; it carries the greater part of the cost of providing service to the consumer and has the greater scope for economic development. There may be cases of backward undertakings, but it can be claimed that authorized undertakers are capable of, and are actively engaged in, the economic development of distribution within their areas, but the policy of statutory control and direction of generation adopted by the legislature, and the appointment of a committee to report and make recommendation on distribution, can be regarded as only steps towards complete control of the whole industry.

Let us hope that whatever steps are taken by Parliament in respect of distribution may not impose further restrictions and additional financial burdens upon the industry.

CONCLUSION

Can it be doubted that the control and direction to which I have referred, coupled with dual administration, are not the end of parliamentary action and that the ultimate end is State ownership? Parliament has from the earliest enactments affecting this industry made provision for public ownership, and the later legislation has so far committed Parliament that the advocates of State ownership can have little difficulty when the political pendulum swings in their favour in making this effective. Already the provisions of the Act of 1926 give to the Central Electricity Board full and undisputed use of generating plant where the loan debt is amortized by the owner of a selected station without payment to the owners for such use, and no corresponding provision is made for this to be reflected in the prices charged for supplies. The best terms that can be obtained is a compromise in the estimates of cost of production under hypothetical independent operation.

It may be urged that State ownership would solve the problem of uniform method of charge and prices and that a service on the lines provided by the General Post Office would result. This policy has already been indicated and might appeal to a credulous public mystified by existing tariffs, but these two public utility services have no real parallel. Electricity supply may, in a limited sense only, be considered monopolistic; it has competitors offering rival services, and industry is not dependent upon statutory sources for its supply.

It is not my purpose to express opinion on the aspect under State ownership but to suggest that the trend of the legislature is so far in that direction that it is inevitable.

This comparatively young industry, which from its inception has been alternately restricted and encouraged by the legislature—such encouragement being qualified by the imposition of financial burdens—may pass through another phase of dual administration before—in my submission—it is dealt with as a whole under the one administration I have indicated—the State itself.

NORTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By S. R. SIVIOUR, Member.

(ABSTRACT *of Address delivered at* LEEDS, *13th October,* 1936.)

I propose to deal with the subject of distribution and to put before you some observations on practical problems and difficulties appertaining to systems operating over large areas. Distribution is responsible for the major portion of the total cost of supply and offers a vast and diversified field for improvement in technique and commercial efficiency. Unlike generation—which is almost entirely a technical problem with most of its troubles contained within the confines of the power-station site—the problem of distribution is one involving many factors. The political factor is of importance, and of late has had much attention focused upon it owing to the issue of the Report of the Committee on Electricity Distribution.

Legislation

I make no excuse for referring to legislative problems first, because statutory undertakers obtain all their powers and privileges and, *per contra*, their obligations from Parliament. To those holding executive positions in supply undertakings operating over large areas, an acquaintance with the relevant statutes is essential, and the daily task is made harder by reason of the large number of Acts concerned, and to the ambiguities which arise by virtue of the application of enactments made for other public services. For instance, the fundamental powers of electricity undertakers to open streets and " do all other acts " are given by the Gas Works Clauses Act, 1847. It was not until the Electric Lighting (Clauses) Act, 1899, that these powers were amplified.

One can understand that in 1847 Parliament could hardly have visualized the " electric age " and much less so the need, for instance, of specific provisions relating to overhead lines, but even in the 1899 Act overhead lines were looked at askance and a veto was provided which is definitely responsible for retarding the early development of supply in this country. This serious restriction was removed by the 1919 Act, since which time development —particularly in the rural areas—has been phenomenal, but the two early Acts referred to still provide the legal basis for the majority of distribution mains work. Small wonder is it, therefore, that with the evolution of technique and altered conditions the early legislation referred to is unsuited to modern conditions and results in contentious points arising, with consequent delay in making supplies available. To illustrate the perplexity of the question, I would remind you that, in addition to the 11 Electricity Acts, undertakers are concerned with provisions in at least a further 43 Acts, a total of 54.

From this I feel you will agree as to the need for consolidating electricity legislation. It is to be hoped that when this is done some useful additional powers, a number of which were included in the defunct Bill of 1933, will be granted.

There is an urgent need for an extension of powers to lay mains in private streets, whether dedicated to the public or not. Electricity is an indispensable public service and it should be made impossible for the biased or obstructing owner or occupier to prevent or delay supply being given except on unprincipled terms. On similar grounds, the power to place service mains on private property should be amended to permit a tenant to exercise his choice of supply without the consent of the landlord where this is unreasonably withheld. In spite of a number of useful concessions by Government departments concerning applications for consent to erect overhead lines, the procedure still involves a great deal of routine work. It would not be unreasonable to give a general consent to undertakers to erect overhead lines—to approved designs if thought necessary—as in the case of underground works, but subject to a reference to the Minister in cases where the local authority objects. The present procedure seems to stand not so much on the need to obtain approval to construction (because undertakers are bound to comply with the Regulations) but to obtain the consent of the Minister to every line as required by the present Acts. It is well to remember that overhead-line supports are " structures " within the meaning of other relevant Acts, and it is preferable from the undertaker's point of view that these lines should continue to be controlled by an authority conversant with the technical and other requirements rather than be subject to local by-laws. A further point concerns Section 21 of the 1919 Act: no specific procedure is laid down, there is no time limit during which objection may be lodged, and delays occur. The majority of local authorities deal with notices promptly, but there should be uniformity in procedure with underground works. It is usual to serve the notices under Sections 21 of 1919 and 14 of 1899 together, but under the present law these are ineffective until consent is obtained under Section 10(*b*) of 1899. Another cause for delay occurs where it is necessary to seek compulsory powers for lopping or cutting trees, as under the existing law it would appear that it is not in order to apply for such powers until the undertaker is entitled to erect the line: thus an additional inquiry may be involved. In the meantime, the consumer waits! All of which goes to show that amendment and simplification are badly needed.

Regulations

By the issue of the Electricity (Supply) Regulations, 1934, the Electricity Commissioners have with one exception codified the whole of the requirements previously covered by several prior codes. The exception is the Overhead Line Regulations El.C. 53 (Revised), and it seems a pity that this was not included between the same covers, as amendments could always be made as an addendum.

There is in this country a high regard, and rightly so, for the safety of life, and so long as the Regulation requirements are in accord with proved practice and experience and recognize both the existing state of the art and the economic factor, they should be accepted as a standard below which it is inadvisable to go. On the whole the Supply Regulations, 1934, are reasonable, but various amendments are under consideration which it is to be hoped will result in further improvement. It is well to remember that undertakers are legally bound to comply with all Regulations, which it must be presumed have been drawn up after due consideration of the rights of the public and statutory bodies. It is therefore unwise to concede demands from other bodies in excess of the Regulation requirements unless the conditions are exceptional.

Wayleaves

Wayleaves are the cause of many delays in making supplies available in rural districts. The 1919 Act greatly improved the position, and to this one can ascribe the tremendous development and use of overhead lines since that date. Unfortunately, the judgment in the Pitt case has created new difficulties and, although it has not limited in any way the power to acquire wayleaves, the fact that pecuniary terms are not dealt with along with the grant of a compulsory wayleave acts as a deterrent in certain cases. It seems rather an anomaly that whilst the Minister may determine the compensation payable under an Order for the lopping of trees he cannot fix the pecuniary terms for placing the line which will interfere with such trees! Legislation is needed to straighten out the existing chaotic position and to provide a procedure for the fixing of economic rentals and compensation satisfactory alike to undertakers and to owners and occupiers of land: nothing would contribute more to the speeding-up of development work in rural areas.

Trouble and delay are occasioned by claims of private owners to the ownership of a marginal strip of land on the side of the highway. It has been held that, in the absence of any evidence to the contrary, the highway extends to the extreme limit of the fences on either side. The highways authority usually stipulates that poles shall be erected close against the fence, and generally the alleged " trespass " is committed in innocence. The acid test is to find out who has maintained the said strip. If it can be proved that the highways authority has done so without objection by the abutting owner, it is fairly certain that it can be proved that the land in question is dedicated by presumption. It ought to be made possible for highway authorities to exercise their rights to the extreme limits of the road boundaries, with compensation to private owners where appropriate.

TRANSMISSION SYSTEM

Security of Supply

By this I mean the continuity of supply to the whole system, and although, fortunately, the cases of widespread disturbance in this country have been comparatively few, the present-day tendency to concentrate generation in a relatively small number of stations calls for careful consideration in the layout of the system. Interconnection of stations is provided for by the grid, and the problem mainly concerns the individual undertaking. The majority of the larger systems in the country commenced operations with 6-kV or 11-kV mains run as radial or ring mains for supply to power consumers and general distribution centres. Development of load has subsequently called for additional generating stations, generally interconnected with the other station or stations, and contemporary with this, or, later, the superimposition of a main transmission system operating at a higher voltage and with the generating plant directly associated with the higher-voltage system. Assuming all the main distribution centres to be connected to the higher-voltage transmission system, it is therefore practicable to provide alternative sources of supply to the lower-voltage distribution system by sectionalizing the mains and feeding them from the main distribution substations. In practice, the 11-kV distribution networks in the area near generating stations are normally fed direct but can be supplied from a main substation under emergency conditions. This method is also applicable to systems with only one generating station, by suitable segregation of the plant and the provision of a main transmission system interconnecting the distribution centres. With the extraordinary growth in plants and systems, we must carry out our extensions to a general plan on these lines and thus provide reasonable safeguards against serious disturbance.

Cables

Less than 10 years ago the state of the cable-manufacturing art as regards the higher pressures was behind the demands of the industry. I need not remind you of the unfortunate experiences in this country and elsewhere with cables for 33 kV and higher pressures. The phenomenal growth of electric power development during the post-War period called for a rapid advance in technique differing from and greatly in excess of existing experience and knowledge. However, thanks to immense activity in research and practical investigations by workers in the manufacturing and supply sides of the industry and on the part of other bodies, a tremendous advance has been made.

A complete answer as to the causation and mechanism of dielectric breakdown has yet to be found, but sufficient progress has been made to permit of the successful manufacture and operation of cables at pressures of 33 kV and 66 kV. A number of installations are in operation at 132 kV and even 220 kV, which is an outstanding performance. The so-called solid or straight type of cable has retained its place, at any rate for 33 kV, owing to the adoption of the earthed metallic screen whereby practically all electrical stress is removed from the filler spaces and ionization therein eliminated. Heat radiation is also improved and this type of cable is better, both electrically and mechanically, than its belted forerunner. It also has the advantage of simplicity in installation and maintenance and still holds the field economically. Whilst admitting the advantages offered by the oil-filled, gas-pressure, and gas-filled cables for the higher voltages, they and their accessories introduce complications which postulate a very high degree of manufacturing and installation perfection, not to mention the difficulty of finding accommodation in streets for the ancillary works, together with, of course, increased maintenance costs. Reliance upon insulation resistance as a measure or criterion of quality is a thing of the past, and it is now recognized that the series of phenomena known as ionization is the important property in high-voltage cables. The ionization factor is an index to the degree of perfection of impregnation and of the presence of voids, and various time/voltage breakdown and stability tests have been devised, and performance limits, which it is claimed will give satisfactory service, have been defined for cables. It may be of interest to state that 3-core 33-kV cables laid down during the past two years have shown a power factor of the order of 0·0030 and an ionization factor seldom exceeding 0·0001 (often zero), over the range of tests from half to double working voltage.

As a usual figure for power factor was 0·0077 in similar cables 10 years ago, the progress made may be considered very satisfactory.

The development of low-loss impregnating compounds, the rigid control of all materials and manufacturing processes, and the use of the Schering bridge with its facility for accurate measurement of very small power factors, are mainly responsible for the vast improvement in cable technique, the incidence of which is reflected in better paper-insulated cables throughout the entire range in common use.

Cable Maintenance

High-voltage cables in particular should be tested with over-voltage after installation as a check on workmanship in laying and jointing, and there is no more suitable method than high-voltage direct current. The portable testing equipments which are available, used in conjunction with a high-voltage bridge, also provide the best method of test for localization of faults and for routine tests on old cables for the purpose of eliminating weak spots before they break down in service.

An annoying cause of cable breakdown is external damage by other bodies. During a period of 5 years on the systems with which I am connected the breakdowns definitely due to this cause amounted to 63 per cent of the total cable failures. Very few local or highway authorities have a complete record of existing sub-surface works, and there is a lack of co-operation between the various bodies having powers to break up streets. We have effected a considerable improvement, partly as the result of an invitation to interested authorities to inspect our large-scale records whenever they desire to carry out work in districts in which we operate, and partly as the result of a general scheme of collaboration.

Protection of Cables against Fire Risks

A fire which occurred about two years ago owing to a switchgear fault in a substation gave rise to the problem of suitable protection for exposed cables terminating in switchgear and transformers. After investigation and experiments we found that by removing the outer serving, cleaning the lead sheath, and lapping over the exposed length of cable between floor and sealing chamber with two layers of 2 in. × $\frac{1}{8}$ in. asbestos tape, afterwards treated with a good coating of silica paint, steel cones being provided over the conduit ends at floor-level, a reasonable measure of security is obtained against this danger. The termination of cables into banks of switchgear is best done by separate conduit entries to the building, completed by the above method of protecting the exposed cable. It is assumed that fire-fighting appliances will be brought into use within a reasonable time. Trenches for cables are sometimes unavoidable: they should be filled with gravel to floor-level and the exposed length of cable treated as already described. In generating stations the problem is more difficult, but the solution seems to lie in the segregation of important cables, and protecting as for substation work.

Cable Jointing

Of the many parts of a supply system where reliance must be placed on the human element, there is none more important than that of cable joints. The standard of workmanship to-day is very good, and with improvements in box design and components this part of the system now gives little cause for anxiety. In this connection I would mention that on a system of 33-kV mains, including over 1 000 joints of all types, there have been only 4 joint failures over a period exceeding 10 years. It is desirable to have a recognized scheme of training for jointers, and a school or centre where this can be carried out provides facilities for this and for trying out new designs or methods before general adoption on the system.

Street Works

A considerable advance has been made in the execution of trench work and the laying of mains by the use of mechanized plant and improved transport. Contemporary with this, however, the highways authorities have had to meet the requirements of modern traffic, with the result that as regards costs we are more or less " as you were," owing to the high cost of breaking up and reinstating reinforced foundations and specialized surface paving. The remedy both from the economic standpoint and also in the interests of the public is to provide suitable grass verges in combination with footpaths and to allocate this space for the use of the public services. This plan has been followed to some extent in the City of Leeds. In the case of all new arterial roads a standard position has been allocated to the public service mains, under which the distribution mains of all the utilities occupy inner positions, ensuring short connections to abutting property, thus giving ease of access, minimum disturbance to the public, and reduced costs. This standardized provision for sub-surface works should be made compulsory in all new road construction. The difficulty of dealing with existing narrow roads is admitted, but some improvement could be effected by applying the principle of a standardized position. The view that the highway exists primarily for the surface user cannot be justified. If the public services of water, light, heat, and communications, were not carried underground, can you imagine the congestion which would be caused by the transport of their corresponding commodities over the surface of the highway?

A difficult problem affecting public utilities concerns road improvements, and, in view of the enormous amount of this class of work which is going on, the matter is a pressing one. The legal position is not satisfactory, but electricity undertakers are better placed than some of the other utilities. It is to be hoped that negotiations now proceeding between the various interests will result in satisfactory arrangements being concluded. It does not seem unreasonable to claim that as road improvements are carried out for the common good they should be paid for accordingly, and that public utilities should be reimbursed for the cost of alterations to their works.

The burden of high costs in trenchwork can be eased a little in new or reconstructed roads by the laying of conduits at road intersections and at equidistant points along the road from side to side in readiness for future cable requirements.

In connection with the foregoing and many other questions affecting statutory undertakers, it seems appropriate to refer to the achievements of the Conjoint Conference of Public Utility Associations, which consists of associations representing the statutory water, gas, and electricity undertakings, and whose work deserves to be more widely known. The Conjoint Conference has been instrumental in obtaining for public utilities (and incidentally for the public they serve) many concessions of a protective nature in statutory enactments relating to all sorts of local government and other measures. Further, differences between utilities have been amicably settled through the agency of the Conference.

Overhead Lines

Thanks to the pioneer work done on many of the power company undertakings and to the subsequent experience in operating, and also to the enormous amount of research and tests carried out by various bodies, overhead-line construction has reached a very high standard. There is still scope for further research in the matter of insulation and in the method of attachment of conductors on the higher-voltage lines. Useful experiments have been and are being made to deal with insulator surface pollution, mainly in the guise of self-cleansing types; in the meantime cleaning at regular intervals is essential in locations subject to contaminating influences. As regards conductor clamps on suspension strings, the essential requirement is good contact between clamp and conductor, otherwise arcing and damage to conductor may result when insulator flashover occurs.

The secret of satisfactory line operation lies in regular inspection and maintenance, and this applies particularly to the insulation. Insulators of the multi-part or unit type all develop ageing characteristics—sometimes after only a few years' life—and frequent examination is necessary. It is now possible to carry out this examination with the lines alive at pressures up to 66 kV. The equipment is of simple design and operates on the principle that whether the insulation be of the multi-part pin or the multi-disc type, the composite insulators possess potential gradients of regular characteristics and by a comparison with similar healthy units any defective unit can be spotted by test and arrangements made to change at a convenient opportunity.

Transformers and Switchgear

It would be fair to say that transformers seldom break down owing to deficiency in design. The occasional failures are practically confined to the pole-mounted type and are usually associated with lightning causing flashover in the head of the transformer due to incomplete immersion of all bare parts in oil. This difficulty has been overcome in some cases by the use of longer shank insulators carrying the connections below oil-level, and in others by the provision of larger tanks. The use of high-speed fuses of the carbon-tetrachloride type has also reduced the risk of damage from severe arcing. On-load tap-changing equipment should be a standard provision on all units of 1 000 kVA and upwards, and also on smaller units to suit particular conditions. Having regard to the relatively complicated nature of this apparatus, easy access for regular inspection and maintenance should be provided, the need for which is greater than in other substation equipment by reason of the frequent operation of the moving contacts.

The use of bakelite for the primary insulation of current transformers has been tried, but trouble occurred owing to a tendency for leakage current to track across the surface with condensation—a condition difficult to counter at all seasons of the year. This experience indicates that bakelite should not be used for high-voltage circuits in air.

Insulator bushings of the oil-filled type call for attention at regular intervals to ensure maintenance of oil-level. The compound-filled type calls for special care in filling and close control of temperature during the cooling period in order to prevent the occlusion of gases. Where doubt exists as to the condition of the earlier type of insulators of this class, recourse may be had to testing equipment which is now available for the accurate measurement of power factor and energy loss under high voltage. As regards bushing insulators which are filled with compound or have shanks buried in compound, as in cable-dividing boxes, experience has shown that a plain unglazed surface for the portion in contact with compound is best: corrugations are liable to trap air, and the unglazed surface ensures better adhesion of the compound.

DISTRIBUTION

I propose to confine my remarks under this section to work in rural areas and low-voltage distribution generally.

Overhead lines are a *sine qua non* for this work and there is no question as to their use in the generality of cases. With this form of construction it is possible to meet the initial demands at the lowest cost—beneficial to the undertakers by accelerating development in all districts, and to the consumer by lower charges than might otherwise obtain. Further, this earlier development has a cumulative effect on load-building, in view of the time required by the average consumer to become electrically minded and increase his use of the supply for other purposes. In the early years of the present rural electrical development the supply industry was accused of desecrating the countryside with so-called pylons—a much misused word applied to every kind of line support from a grid tower to small distribution poles—but thanks to recognition by the public of the economics of the case and to the policy of supply authorities in erecting lines of neat design carefully sited so as to cause a minimum of interference with amenities, the opposition to this form of construction has now almost disappeared.

The difficulty of dealing with the isolated farm or other premises in rural areas largely concerns the cost of the high-voltage line and equipment. The solution in most cases is the use of a single-phase steel-conductor line, with fuse protection to the branch line at the point of tee-off and the solid connection of the transformer on the primary, protective switchgear being provided on the l.t. side only.

The long straggling village is a difficulty and frequently calls for two high-voltage feeding points spaced at the economic distribution distance on each side of the centre, thus allowing for growth outwards. As an interim stage, one supply point in conjunction with pillar- or pole-mounted regulator will probably serve for several years.

There is no question as to the efficiency of the 3-phase 4-wire a.c. system of distribution for the built-up urban area, but in the smaller villages and isolated groups of premises there is every justification for the use of single-phase 3-wire distribution, with a capacity approximately 4 times that of single-phase 2-wire. The secondary winding of all single-phase transformers should be in halves so arranged that the half windings may be connected in series to give a 460/230-volt 3-wire supply, or in parallel to give a straight 230-volt 2-wire supply. Where there is a possibility of power load or of extensive building the poles can be provided to allow for the additional wire when required, and this, together with a change of transformer, will convert to 3-phase 4-wire at very small additional cost. The modern single-phase motor is practically equal in performance to the 3-phase machine and its cost has been greatly reduced; the latter point removes a former difficulty in regard to the consumer's installation cost.

The economic size of line conductor for l.t. distribution is generally 0·10 sq. in. and there is very little advantage in using a larger conductor. Both in relation to voltage-drop and cost, and where there is a reasonable chance of further development, a cable can usually be justified where the load calls for a larger conductor. In addition, there is nothing more unsightly along our highways than very large conductors carried on heavy poles.

Every avenue for reducing the capital charges on distribution is worthy of attention. The British Standards Specification No. 480—1933 represents a useful contribution by the cable industry towards a reduction in these costs. Experience and research has shown a large margin of safety in the old B.S.S. No. 7—1926, and for all straightforward distribution mains I see no reason for not adopting the 460-volt grade. This represents an average reduction in the cost of cable, as compared with the earlier specification, of the order of 10 per cent, or on the total cost of the cable laid of about 5 to 6 per cent. Further, by reason of the smaller diameter of the cables, a small saving is effected in joint boxes. These so-called "beltless" cables require more careful treatment in jointing operations, but with the aid of a new technique under which those anachronisms in cable-jointing, a hack knife and its complementary 2-lb. hammer, are relegated to a more suitable sphere, this difficulty has been overcome. The method involves the use of only a knife and pliers and is applicable to all cables; the introduction of these small beltless cables has therefore brought about a specific improvement in jointing technique. As regards cables for internal installations, usually involving numerous bends and much handling, and for mining and similar work, the 1 000-volt grade is desirable.

There appears to be considerable diversity of opinion and practice concerning the size of the neutral conductor in 3-phase distribution mains. Under the predominance of single-phase apparatus with diversity of use and location (and particularly so in the early stages of development) good balance is unattainable. It is not practicable to ascertain the current in the neutral in all parts of the distribution system, but it is possible to do so at sectionalizing points. From tests carried out on one l.t. network over a period of two weeks it was found that the out-of-balance current in the neutral as recorded at sectionalizing points at no time exceeded 36 per cent, and it would not be unreasonable to assume that on that particular network the worst out-of-balance did not amount to more than 50–60 per cent. Admittedly the conditions on any network will vary, but with the provision of a suitable proportion of 3-phase "balancing" services, i.e. those giving a normal single-phase supply to the consumer but providing facilities for re-balancing when conditions alter, the out-of-balance may be kept within reasonable limits. For distributors up to and including 0·10 sq. in. the neutral should be of the same size as the phases, but above 0·10 sq. in. a neutral of approximately 75 per cent of the cross-section of the phase conductors is sufficient. Taking the four sizes of 0·15, 0·20, 0·25, and 0·30 sq. in., the saving in cost on the cable only is of the order of 4 per cent. With overhead lines it is preferable for other reasons to provide a full-size neutral.

The foregoing suggestions in regard to savings may be small individually, but in the aggregate, and in conjunction with reductions in the cost of service details, trenching, etc., may amount to an appreciable sum. As regards cables in particular, probably a greater reduction could be obtained by standardizing a small number of sizes to one uniform specification, as has been suggested.

There are divergent views on the question of providing a double-pole fuse or alternatively a single fuse and solid link for the neutral. Admittedly each method has its merits, and it is purely a matter of weighing up not only the advantages and disadvantages of each method under specified fault or abnormal conditions but the chances of those conditions arising. From my own knowledge I can say that with nearly 100 000 house services, and over a period of 30 years, no difficulty or damage has been experienced owing to the use of a solid link in the neutral.

GENERAL

Voltage Regulation

The maintenance of the declared voltage to consumers within the permissible limits is a problem which has become accentuated by the phenomenal growth of systems and the successful exploitation of the domestic load. There is a considerable difference between the conditions obtaining in the built-up urban areas and in the more thinly populated and rural areas so far as the economics of the case are concerned. In the former a bold policy of providing ample copper against the existing potential load can be safely followed, but in the latter the increased length of mains per consumer, the unknown development, and the fact that in country districts the spending power of the people is generally less than in the towns, make it necessary to " cut the cloth " rather more closely. At the same time there is nothing more damaging to the reputation of the supply service than unsatisfactory quality or reliability, and the provision of a reasonable margin of spare capacity and protective equipment, even against initial economic balance, will usually result in accelerated development. We are, however, faced from time to time with the need for reinforcement. The particular conditions and requirements will dictate what method to adopt, but there are many cases which justify an interim measure of relief. This can be provided by automatic equipment in the form of voltage regulators: very often a balancer alone will meet the requirements.

Street Lighting

The question of street lighting has been brought to the prominence it deserves, and with the prospect of national control of the main roads it is reasonable to assume that a uniform standard of efficient illumination will be specified. The development of the high-efficiency electric discharge lamp should leave little doubt in the minds of the highway authorities as to the illuminant to be adopted, and it behoves electricity undertakers to be ready to deal with this important load. Further, the load represented by the lighting of the minor roads of township or village is well worth obtaining. The load factor is good and the acquisition of this business frequently takes the distribution mains into streets which would otherwise await normal development. Much research has been and is being carried out on the problems associated with the standard of illumination, height and spacing of the units, and complementary matters relating to road surfaces.

It is now almost essential that street lighting should be controlled so as to be capable of extinction at a moment's notice, and in this respect electricity offers great advantages. The following constitute the usual methods of supply and control:—

(*a*) An additional conductor (switch wire) in the normal multi-core distribution cable or overhead line, with time-switch control at substations or other feeding points.

(*b*) A separate cable for street lighting only, with time-switch control.

(*c*) The tapping of the general distribution main, with control by individual time-switches at the lamps.

(*d*) As for (*c*), but with control by high-frequency impulses actuating a relay at the lamps.

In my view, (*a*) provides the most convenient and certainly the most economic method, and generally it would be sound policy to provide the switch wire throughout all networks. This policy has been adopted on the systems of the associated companies with which I am connected, and although in some cases we have had to wait some years before the street-lighting business matured, the additional cost of the fifth core on the underground sections has amply justified itself. On overhead systems it is only necessary to provide initially suitable poles, and to add the extra wire when required. The additional cost of the fifth core under method (*a*) is about 8½d. per yard for the usual range of distributors (say 0·10 sq. in. to 0·20 sq. in.), so that for the recommended lamp spacing of 50 yards the cost of the circuit amounts to 35s. 5d. per lamp. The additional conductor is revenue-earning and, with a suitable impulse system, is capable of being used for other subsidiary purposes of control. Method (*b*) is more costly than (*a*) and has the disadvantage of introducing a small cable which is mechanically weak and, unless laid at the same time as the main distribution cable, this scheme is decidedly uneconomic. Method (*c*) is only comparable when synchronous time-switches are used, and even then has disadvantages. The last method (*d*) has distinct possibilities, but the systems at present available do not appear to be capable of general application to overhead or mixed systems of distribution, nor is there any advantage in cost.

CONCLUSION

It is recognized to-day that the supply of electricity is a public service of the greatest importance. Its place in industry for power and other requirements is undisputed, and the past decade has seen a remarkable advance in its adoption for all domestic uses. In the last five years the number of consumers in this country increased from 3½ to nearly 7 millions, and at the present rate of growth it would be reasonable to assume that in another five years substantial progress will have been made towards saturation point in the domestic field.

Whilst there may be much truth in the slogan that " electricity sells itself " it is none the less true that there is a vast untapped load to be obtained over and above that part such as lighting and other services which the public now demand by virtue of efficiency and convenience, and which can only be obtained by active investigation and co-operation between all sections of the supply industry. We have talked for years about the valleys in our load curves, but they still leave ample scope for filling by the use of off-peak energy for thermal and other purposes. It therefore rests with all of us to continue and intensify our energies in our several spheres. We have a splendid record of endeavour and achievement behind us and I feel sure that with that tradition—for it is untrue to say the industry is in its infancy—we shall soon have a public which is a long way towards being 100 per cent electrically minded.

SOUTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By E. A. REYNOLDS, M.A., Member.

"THE DEVELOPMENT OF THE ELECTRIC LOAD"

(*Address delivered at* BIRMINGHAM, *14th October*, 1936.)

The electrical supply of this country has now been co-ordinated under the Central Board for the generation of electric power, and through the interconnection of the power stations by means of the grid there is now available a large reserve of electric power. The important question at present is: How can a load be developed to absorb this reserve economically? The object of this Address is to point to some of the directions in which there are possibilities of the development which is necessary for the justification of the grid.

DEVELOPMENT OF COMMERCIAL LOAD

The use of electricity for motive power in factories is now generally accepted, and no special effort is necessary to increase the load in this direction, as its adaptability to all manufacturing processes and its simplicity of expansion and extension is so obvious that this load will automatically increase, the rate of this increase being partly dependent on the condition of trade. In addition, however, there will also be a considerable extension of the use of electric motors owing to their superseding other forms of power at present in use. There are, however, many directions in which the factory load can be extended electrically. These are not yet fully appreciated, although in some processes electrical methods are making rapid progress through the spread of knowledge of what has been achieved, and the skill and ingenuity of manufacturers of electrical apparatus in adapting their products to the varied requirements of the different trades.

The most widely used electrical manufacturing process is that of welding, and in many of the varied trades dealing with ferrous metal it has a recognized place. Welding originated on the blacksmith's hearth, but now the two main welding processes are oxy-acetylene and electric. Each of these has its own particular uses and they are developing side by side; both have possibilities of great expansion in the manufacture of articles in conjunction with presses and drop stamps. One of the advantages held by electric welding over other forms is in the direction of repetition work, on account of the ease with which the weld can be controlled and the fact that by suitable arrangements this control can be so completely automatic that the welding apparatus can be operated by unskilled workers; such repetition work is now usually carried out by girls. For small work spot welders are used, and for many purposes the period of the weld is controlled mechanically, but for welding thin metal the period must be very short and of an exact value, and for this purpose a control has been devised which uses a thyratron valve as the controlling switch. With this the period of a weld can be set as low as 2 cycles of the alternating current, and this period will be absolutely constant. This type of controller can also be arranged to give an even succession of such welds at any required spacing along a seam and, when this is set, work can be carried out with perfect welds by unskilled labour.

This method of welding makes a joint along a seam very similar to that of an ordinary sewing machine and is used, amongst other purposes, for building up sheet-metal motor-car bodies.

For continuous seam-joining flash-welding is used. This is the method adopted for welded steel tubes and other purposes and is now a standard manufacturing process. Welding is also used for building-up fabricated articles other than light repetition work, the individual parts of the article consisting of pressings, drop forgings, drawn tubes, etc. The parts are clamped in jigs, and the weld takes place under heavy pressure, mechanical or hydraulic. This method saves the cost of machining parts out of solid castings, with the advantage of additional strength in the articles so made.

Another form of load which deals with large power units is that of melting and mixing furnaces for metals. In Great Britain this load now totals about 150 000 kW with a consumption of probably 450 million units per annum, but this is low in comparison with that in other countries and should show a large progressive increase in the near future. The world power consumption for this purpose is estimated at 8 000 million kWh per annum, to which Germany contributes 2 000 million kWh with 450 000 kW installed.

The only limit to the use of such furnaces is that of temperature, which cannot exceed 1 200° C.

In addition to providing the high temperatures required for melting, electric furnaces are used for a large variety of purposes at medium and fairly low temperatures.

In actual practice one of the main advantages of the use of electricity for commercial heating is the ease with which it can be controlled within very close limits, and the accuracy with which any desired temperature can be maintained. Another very definite advantage is of course the absence of fuel and its accompanying dirt and ashes in the factory.

Time clocks are often used in connection with relays for starting up these furnaces before the working day commences in order to bring them up to the working temperature at the ordinary starting-time of the factory. As they are thermostatically controlled there is no risk of the normal temperature being exceeded during this period, although they are receiving no attention whatever. For these reasons there is enormous scope for electrically-heated furnaces over a wide range of low temperatures for varied manufacturing processes.

Of these, perhaps the most general is that of annealing in factories producing tube, strip, and wire, and articles made out of these, and owing to the absence of any products of combustion such furnaces can readily be designed to prevent oxidation and chemical action during the process of heating, with the result that the materials remain bright and do not require pickling to restore the surface.

Electric annealing furnaces are now in general use for steel, brass, copper, and aluminium alloys, some of the larger ones installed being up to 180 kW capacity each; in some factories the whole of the annealing throughout all processes is carried out electrically.

In extruding presses the temperature of the billet is a very important factor, and electric heating is eminently suitable for this purpose owing to the ease with which a constant temperature can be produced and maintained.

Electricity has been proved to be economical for small annealing furnaces dealing with metal parts in the process of manufacture, such as pressings and drop forgings, and compares very favourably with other forms of heating. The use of such furnaces is extending, and as they are all automatically controlled a large number of these comparatively small units will give a very useful additional load that is fairly constant over long hours owing to their high diversity factor.

Special forms of these furnaces consist of several chambers in which the material is heated in an inert gas in one chamber and then passed through to a similarly filled chamber in which to cool, sealing chambers being provided for introducing and extracting the articles to be annealed. This results in bright annealing without any oxidation or scaling, and this method is also adapted for the continuous annealing of wire and strip.

In some cases furnaces are required for a low temperature for normalizing finished drawn tubes or wire. These can be designed very easily for electrical heating, as quite low loading of the resistances can be arranged to provide an even temperature throughout long lengths of muffles and this is rather difficult of achievement with the use of incandescent gases.

Small furnaces working at a high temperature are being extensively used for tool-hardening and tempering because of their adaptability, and the absence of the necessity of conducting away any harmful gases renders them capable of being moved to any required position.

Another form of furnace is that of enamelling stoves, and in these one of the advantages of electric heating is cleanliness in the stove and the absence of dust.

For the quite low temperatures which are required in drying chambers, low-temperature units such as tubular heaters may be used in conjunction with natural air-displacement or high-temperature heaters over which air is driven by fans. Insulated low-temperature heaters are also used in plating vats which require to be heated.

For a large number of purposes press tools require to be kept hot at a constant temperature. For this purpose flat strip heaters enclosed in metal cases provide the most suitable form of heat as they can be rigidly clamped in recesses between metal surfaces, and thermostats are fitted to maintain the required temperature. Among the processes for which these are used are bakelite moulding, making stereos for printing, bookbinding, calendering rolls, etc. From the examples given above it will be recognized that there are very many industrial processes in which electricity can be advantageously used.

The extent to which electricity will be used for these purposes depends naturally on the charge per unit, and at $\frac{1}{2}$d. per unit, which is the rate for a commercial heating load in several undertakings, electricity has been proved in many cases to be able to compete economically with any other form of heating. In any factory where it has been introduced this load shows a continual increase until every process where heat at any temperature is required has been converted to utilize electricity for that purpose.

The rate of $\frac{1}{2}$d. per unit for commercial heating usually has the restriction that it cannot be used during the peak hours in winter afternoons, but in practice this is found not to be of really serious importance and whatever disturbance is entailed in factory routine is counterbalanced by the very decided advantages of economy, ease of control, adaptability to extension, cleanliness, uniformity of temperature, and healthier conditions for the operatives, due to the absence of fumes and products of combustion.

In the heating furnaces which have been mentioned, the heating is obtained by resistances embedded in or built into the walls, but there is another form of heating metal which is now being developed for special purposes, and that is by means of induction. The advantage of this process is that the metal is heated from the interior outwards instead of from the surface inwards, and because of this there is no deterioration of the surface through the transfer of heat at a high temperature. This process is also more economical, as there is no heat wasted in heating up the body of a furnace and the consequential loss in radiation. The action is also quick, adapts itself to accurate control, and is of particular use in many small repetition processes in which part of a steel rod only is to be heated for upsetting, bending, or swaging; and the apparatus can be fitted as an integral part of a machine.

As independent portable units, induction heaters are also used for heating rivets.

As this form of heating becomes more widely appreciated, it is fairly obvious that it will be adapted to many different manufacturing processes.

DEVELOPMENT OF DOMESTIC LOAD

The domestic load has shown very gratifying progress in the last few years and now represents about one-third of the total consumption and 61 per cent of the revenue, so that the possibilities of its extension merit very close consideration.

The large increases in the numbers of domestic consumers that are so proudly advertised by different supply authorities are not a correct estimate of real progress, as the consumption of a large majority of these is entirely for lighting and, as so many of the houses are small and the installation consists of only from 4 to 7 lamps, the amount of revenue collected from them is ridiculously small. In many cases it is now recognized that many of the assisted wiring installations on prepayment meters are a definite burden on the supply authority, as the amounts collected from the meters will probably take about 20 years to liquidate the cost of the installation.

A lighting load by itself is affected very little by diversity factor and thus does not assist in improving the load factor of the supply but rather the reverse as the mains are idle for so long a time each day, and consumers will only be a real asset to the industry when they have advanced to the position of users of electricity for domestic purposes other than lighting.

The only measure of true development is a progressive increase in the number of units consumed per connected service, and this is the underlying principle of the 2-part domestic tariff, which has the effect of reducing the total cost per unit as the consumption is increased. The figure in which a progressive authority should take a pride is the proportion of consumers who are taking advantage of the 2-part tariff and thus enjoying the comforts of an electric home and at the same time assisting the development of the electric load.

It is found that diversity factor enters into the domestic load much more than might be expected, and the more apparatus there is in use on services along a main the better is the load curve, and on analysing figures of various undertakings it is found that a large and extensive domestic load has almost as good a load factor as a factory power-load. The slow growth of electrical apparatus in use, compared with the large increase in new consumers, is due to the widespread idea in many quarters that electricity is an expensive luxury for other purposes besides lighting whereas the reverse is possibly the case, as is recognized by the high rates for lighting only and the low rates on 2-part tariffs. Electricity in the home is definitely a luxury, but with the low rates that exist in many districts consumers find that it is a luxury within the reach of all classes of the community.

The 2-part tariff is the most rational method of charging for electric supply, as it consists of an annual charge which represents the availability of supply according to the size of the house, and a low rate per unit for all current consumed, and, if this were the generally accepted method of charging, consumers would naturally estimate the running cost of additional apparatus on the low rate per unit only, which is quite a correct assumption, and in progressive undertakings where, through propaganda, the 2-part tariff has been adopted by the majority of domestic consumers a very satisfactory increase in domestic consumption has ensued, as is revealed in published reports.

Although the extension of the domestic load depends in a large measure on the rate at which the public become electrically-minded, there is a retarding factor in the high rates that are charged in some districts. Because of this there is a tendency to stagnation as the consumer does not increase his load because it is not an economical proposition to do so, and the rate remains high because for the supply authority it is not economical to reduce it on the consumption that the mains are carrying. Some far-sighted supply engineers have freed their undertakings from this stranglehold by breaking away from the theory of economics and reducing their rates below the economic level based on existing conditions. In the opinion of some critics they are heading for disaster, but they have shown that their bold tactics have resulted in a large increase in load and improved load factor. The result of this has been so satisfactory financially that further lowering of rates has been possible.

In most thickly-populated centres the number of consumers on the 2-part tariff and low rates per unit is showing a fairly satisfactory rate of increase, but on the higher rates charged in country areas conditions are not so satisfactory and it would appear that the only method of attaining the ultimate aim of electricity for every purpose in the home would be to treat distribution as a whole and reduce the differences between the rates for large towns and country areas. This would present difficulties to many undertakings whose area consists mainly of country districts, but this difficulty may not be so acute in the near future if some of the findings of the MacGowan Committee as regards amalgamation of undertakings come to fruition.

If the rate per unit on a 2-part tariff does not exceed ¾d., experience has shown that electricity can compete economically with other forms of energy for all domestic purposes, and this load will definitely show an increased consumption per service connection, and in addition a satisfactory improvement in load factor, and as the rate is lowered below ¾d. the more rapid will be the increase in consumption. Domestic consumers are always ready to attain to the luxury of full use of electricity in the home as soon as they are able to realize that the luxury will be economical, and the best canvasser for domestic apparatus is the satisfied consumer who can show to his neighbours the actual savings that can be effected by the use of electricity.

In districts where the rate has been reduced to ½d. or less, there should be a large rise in the rate of increase of the domestic load, as at present the connected load is only a very small fraction of that for which electricity can show economical results.

The domestic load is mainly composed of cookers, water heaters, and radiators, and the rate at which the use of all these is increasing in areas where the unit charge of ¾d. and less is in existence is an indication of future possibilities in this direction.

The fact that their use is economical is borne out by the number of cookers and water heaters that have been fitted in comparatively small houses where the weekly budget is a very important problem, and in some of these the installation of storage heater tanks is regarded as one of the greatest boons that electricity has been able to provide. This is particularly so in the case of households where every member is away for the whole or part of the day, as there is always a supply of hot water awaiting their return.

In districts where well-directed propaganda has been employed and low rates are available there has been a remarkable increase in the number of water heaters installed, and as the majority of electric water heaters are supplementary to the ordinary kitchen boiler this load reaches its maximum in the summer months when that of domestic heating is at its lowest, and thus does not impose much extra load on the distribution system.

On the low rates available in many districts there is a large field for extension in the use of low-temperature heaters. These are principally employed for raising the temperature of living-rooms and halls and preventing down-draughts from windows. This use of electricity is definitely a luxury in the same way as central heating by hot water, but the additional comfort will often be considered worth the extra cost, especially as with thermostatic control no attention whatever is required.

This form of heating can take the form of either convection or radiation. In the first method, tubular or other forms of heaters are used to raise the temperature of the air in the same way as with an ordinary hot-water system. In the second method low-temperature radiation is arranged from large areas of ceilings or walls, and a comfortable effect of warmth is experienced without the air being very appreciably raised in temperature, the result being somewhat similar to the effect of the sun's heat at winter sports in Switzerland. Owing to the extra advantages of health and hygiene which this form of heating gives, it will undoubtedly show considerable development in the future.

The load taken by such general heating is very acceptable to the undertaking, as it is naturally a long-hour load and, being thermostatically controlled, has a very satisfactory load factor when a large number of installations are in use on the mains.

As the daytime load increases and, in consequence, heavy capital cost is incurred in distribution and generating equipment, the question of the use of the available power during the night evokes increased interest. The supply authority can deal with a load restricted to night time at very low rates and yet show a fair profit, as the distribution network and generating stations are almost completely idle at this time and the rates charged can be based almost solely on generation costs. In the Midland area there are available many thousands of kW for use at night time at these low rates, and this is waiting for load to utilize it. In various ways advantage will be taken of these rates before long, when the real economy of this load will be fully realized by the consumer.

One form of night load that is already in use to some extent and will extend very considerably is that of bulk water-heating for blocks of offices, flats, and public buildings. The system is similar to an ordinary hot-water system which is served by hot-water storage tanks which have to be of sufficient capacity to supply the whole of the heated water for the day's consumption. The water in these is heated during the night by means of electric circulating boilers controlled by time clocks so that they are only in use during the restricted hours. The whole of the installation is completely automatic, both for the heating of the water at night and for controlling the circulation of hot water throughout the heating system during the daytime.

When this system is installed for blocks of flats it is used both for domestic hot water and general heating, and from figures that have been published it has been shown that with current at 0·25d. per unit hot water for all purposes can be supplied to each tenant at an average of 1s. 10d. per week during the year, the consumption of a block of 50 flats being about 850 units per night. Many large supply authorities are in a position to supply current at this rate or even at a lower one between 10 p.m. and 7 a.m. and would be very pleased to have several such consumers on their mains taking a daily load of that magnitude.

This system of heating has also been used successfully for the whole of the heating required in public swimming baths. It has been shown that with current at 0·3d. per unit the cost per annum is less than that for steam heating in a similar establishment, so that at rates lower than that, which are now available in some large undertakings, we may expect the extension of the system to many other baths, with a large steady addition to the night load on the mains. As hot water is required for heating the building and also for the baths, it is advisable to have two separate installations, with arrangements for interconnecting them so that either can be used for both purposes if necessary.

This is the most economical arrangement for running, as hot water is required all the year round and the heating of the building is not required for some months in the summer. The load is naturally variable during the year, but that during the summer is quite appreciable and for most of the year the consumption is in the region of some thousands of units per night. For a public swimming bath of average size the capacity of the two electric boilers would be 400 kW and 120 kW respectively, which represents a very useful addition to the night load of a supply authority.

One appreciable night load which has not received sufficient attention up to the present is the heating of the small greenhouse of the amateur gardener. There are many thousands of these in existence, and any of these householders would hail with joy an automatic heating apparatus on the electric mains that would not necessitate the unpleasant work of attending to the greenhouse fire on a winter's night.

This heating by electricity can take various forms, the usual method for small houses being the use of low-temperature tubular heaters controlled by thermostats. Another method is that of electrically heating a boiler with the ordinary hot-water circulation.

In addition to space-heating of the house, there are now available soil-heating cables fitted with thermostats for burying under the surface of open beds in order to maintain the soil at a constant temperature. This adds enormously to the usefulness of the greenhouse and should appeal to any enthusiastic gardener. This load is almost entirely an off-peak one as it is usually out of action during the daytime, and for this reason its development should appeal to the supply authority, who should be able to give specially low rates for it.

Another form of night load that at present represents an appreciable consumption is that of battery charging for commercial electric motor vehicles and trucks. There are about 2 500 vehicles at present on the road and these absorb about 250 000 kWh per week, and in addition there is the load taken by electric trucks in factories, of which a large number are in use. When the economy of these electric vehicles is more fully recognized, there will be a large increase in the number of them in commission.

LARGE-SCALE COOKING

Although electricity has been proved to be economical for domestic cooking at the low rates in use in many districts, not much progress has been made until recently in large-scale cooking for restaurants and works canteens, institutions, and hospitals. As might be expected, the running costs of the large electric kitchens that are in existence show very satisfactory results from the point of view of economy in comparison with other forms of heating. The consumption in large institutions should be about 0·5 unit per person per day, as compared with about 1 unit for domestic cooking, and as the load is spread over long hours fairly low rates can be charged by the supply authority and yet show a fair margin of profit. This load has not made the progress that it should do, as in 1917 it was estimated that the connected load was 22 000 kW and even now it is only about 70 000 kW. In a paper read last June before the Incorporated Municipal Electrical Association by Messrs. Harvey and Swale an estimate of the possible load was given as 1 million kW with a consumption of 900 million kWh per annum, so that it is obvious that a very large increase in this load is to be expected in the next few years. The rate at which this is achieved, however, depends on propaganda work in this direction, so that when the equipment of such kitchens is being considered electrical methods should take their place on a level with other methods of heating for cooking purposes, as, through a lack of knowledge on the part of engineers and committees of the possibilities of electric cooking in economy and ease of working, its consideration for institution kitchens has not had the serious attention that is its due.

Another form of night load that can show considerable expansion is that of bakeries, where electricity is now universally used for motive power for mechanical processes, but its use can be extended for heating the ovens and all the other purposes for which heat is required. As the temperature of the different ovens can be adjusted to work within very close limits, the advantages of electric control can be readily appreciated.

OTHER POSSIBLE DEVELOPMENTS

There are other important directions in which electricity is making good progress, and which will absorb a much larger proportion of the load in the near future. Some of these are at present the subject of much discussion and interest and for that reason need only be briefly referred to. They are street lighting and railway electrification, which are of such great importance, and consideration of which introduces such involved questions that they cannot be dealt with in the limits of this Address. It is, however, very definite that the loads which they will take in the very near future will show rapid increases and will add very considerably to the total electric load of the country.

There are also the electric processes of smelting ores, the existing load of which is now very considerable, especially in the manufacture of aluminium. This process is now being extended to other metals so that there will be more electricity used, but in many cases this load is not taken from the grid as the consumption is so heavy that it is found to be economical to install individual generating plant for this purpose.

From these references to the varied directions in which development will take place we can safely say that the saturation point is still far distant and that our industry will still maintain its position as the most progressive one in existence, and that we can look forward to its future development with every confidence.

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE: CHAIRMAN'S ADDRESS

By F. E. SPENCER, Member.

"THE DOMESTIC LOAD"

(*Address delivered at* LIVERPOOL, 19*th October*, 1936.)

I offer no apology for taking "The Domestic Load" as the subject of my Address to you to-night. It is becoming increasingly evident that in the near future this branch of the electricity supply industry is destined to play a most important part in the lives of the people of this country.

The difficulty in obtaining domestic help has contributed in a large degree to the rapid growth of the domestic load in recent years, and there is also the fact that conditions of life have altered considerably. Twenty to thirty years ago people stayed at home doing housework, whereas in these days of motor-cars, attractive road-houses, and swimming pools, very much more time is spent in the open air.

To this end, electric labour-saving devices have contributed very largely. The effect is cumulative, as the absence of domestic help means fewer people to cater for and less dirt to clear up.

These changing conditions, therefore, have provided a good field for the supply industry. It only remains for the industry to develop the business, firstly by means of cheap electricity, secondly by the provision of facilities for easy purchase of consuming devices, and thirdly (but by no means the least important) by prompt and efficient service.

Some few years ago it was the fashion with quite a few supply engineers to ignore completely, or at least to pay very little attention to, the domestic load, and to devote the major portion of their energies to securing large blocks of power load, very often at prices which were barely remunerative. This large power load swelled the returns of units sold and plant capacity and made quite a good showing in the annual report. It must be admitted, too, that it contributed towards the general reduction of costs of production and in many cases enabled the domestic tariff to be lowered.

It has always appeared to me, however, that the real function of a supply authority (at any rate a municipal supply authority) is not to find capital and lay down plant for the supply of electricity at cut prices to large users, but rather to provide a cheap service to the individual members of the community, who in many cases have not the necessary capital forthcoming.

I maintain, therefore, that from the point of view of service to the community the domestic load is the most important section of the supply business.

That this fact is becoming more generally realized is apparent from the statistical returns of the industry. The growth of the domestic load in recent years has been phenomenal, particularly in those cases where progressive sales methods have been adopted. Many engineers and managers have at last realized that electricity is a commodity which has to be sold just like any other. It is true that it is one of the easiest of commodities to sell and that up to a certain point it will sell itself, but it is equally true that by an energetic sales campaign the output can be trebled or quadrupled in a comparatively short space of time, with a measure of satisfaction which is shared by a large section of the community as well as by the industry itself.

Now as to the principal uses for domestic electricity. Electric lighting may, of course, be taken for granted, as no private owner or speculative builder will think of erecting a house or developing an estate unless electric light can be installed.

Under the heading of what may be termed the domestic power load, perhaps the most important item is the cooker. It was the fashion, only a few years ago, for the advocates of other forms of cooking to ridicule the competition of electricity in this particular field. This attitude of amused tolerance has now turned to one of distinct alarm. Attempts are still made to try to frighten consumers with the bogy of expense, but experience has shown that with a two-part tariff and a secondary charge of ½d. per unit, cooking by electricity is as cheap as, if not cheaper than, cooking by any other means.

Moreover, the housewife of to-day does not merely think in terms of the quarterly bill; she takes into account other factors such as cleanliness, health, and the saving of labour.

The progress made in recent years in the advance of electric cooking has been most gratifying. In my own undertaking a steady output of about 700 cookers per annum has been maintained over the past few years, increasing to 1 200 last year.

Next in importance may be reckoned the water-heating load. A popular form of water heating is that of an immersion heater or circulator fitted as an auxiliary to the ordinary household hot-water apparatus. This type appeals to the householder, as no interference with the existing system is necessary and the apparatus can be installed cheaply and quickly. In my own area approximately 3 000 kW per annum of this apparatus has been installed in the past 2 years. Some undertakings favour the thermal-storage cylinder and are showing excellent results, but it is not so simple to install and it is certainly more expensive.

Electric heating is well established, particularly for occasional use. The love of an open coal fire which can be poked is ingrained in the Englishman, and it will be many years before that form of room heating is displaced. The portable fire is, up to the present, the most popular form, though many consumers are now installing tubular heating near the skirting boards. Panel and ceiling heating is making slow progress, principally, I think, on account of the expense of installation.

Builders and architects are slowly being brought to realize the advantages of fitting inset fires in bedrooms. A fire in one's bedroom is a luxury only indulged in by the well-to-do, but in case of sickness it becomes a necessity in any house and the electric fire is the most convenient and healthy form of heating. Some architects argue that a coal fireplace is necessary in a bedroom for ventilation purposes, but to me it seems a crude method of ventilation and it should not be beyond the capabilities of architects to devise an efficient substitute.

The wash boiler is another useful piece of apparatus. The annual consumption may not amount to much, but it is an all-the-year-round load and has a good diversity. Moreover, the wash boiler is very often the last remaining household appliance to be changed over to electricity, and every effort should be made to increase its popularity.

Then come the numerous appliances the consumption of which is not heavy, but which, because of their convenience and usefulness, form a most important part of the household equipment. Under this heading come the vacuum cleaner, iron, washing machine, hair dryer, kettle, and other appliances too numerous to mention here. Last, but not least, comes the radio.

A few years ago many supply engineers deemed radio to be nothing but a nuisance, especially when changing over from direct to alternating current, but I think that to-day they all recognize the great help radio has been in advancing the supply of electricity. In my own town I know that it has been the means of converting many hundreds of houses to electricity, a large proportion of which have been the smaller type of houses. So far as I am aware, not one of our competitors has, as yet, put forward an " all-mains " radio set.

At first thought the radio load might appear to be insignificant, but its effect upon the load curve was proved on the night of the last general election. At 1 a.m., when the results were being broadcast, our load was 5 100 kW as against 2 800 kW on the previous night, an increase of 82 per cent. No doubt this increase was not all being used by the wireless sets themselves; a large proportion would be due to extra lighting, electric fires, etc., required in consequence of the broadcast. Similar results have been observed during the broadcasting of important public events.

I come now to consider the value of the domestic load to the supply undertaking. In some quarters we have been criticized for offering low tariffs to encourage the sales of domestic electricity, but a number of figures have been given in recent years which prove clearly that the tariffs are sound economically.

The published statistics show that the load factors of all supply undertakings are steadily improving year by year, and in my opinion this is largely due to the growth of the domestic load.

The diversity of the load is very great indeed. For example, in my own undertaking the load connected has risen in the last 10 years from 20 000 kW to 145 000 kW, an increase of 625 per cent. During the same period the maximum demand on the undertaking has risen from 6 000 kW to 19 000 kW, or 216 per cent. Ten years ago the maximum demand amounted to 30 per cent of the connected load, whereas last year it reached 13 per cent only.

Another important point is the effect that the domestic load has upon the incidence of the peak. Many undertakings, including our own, have found that the continued growth of this load has shifted their peak from evening to breakfast time. In 1933 and in 1935 our peak load for the year occurred at 8–8.30 a.m. and I have no doubt that, but for the exceptionally mild weather in December, 1934, the peak would have been registered in the morning in that year also. The domestic requirements have also had the effect of flattening the evening peak and removing it from 4.45 p.m., as in former days, to about 6–6.30 p.m. The large cities with their huge shop and office demand in the late afternoon will probably take some few years to reach this position.

Next, let us consider how this load can be encouraged. The first essential is, of course, a suitable and attractive tariff. The supply industry is being freely criticized for having far too great a multiplicity of fancy tariffs, but it seems to be generally agreed that the two-part tariff with a low secondary charge and a primary charge based on either the rateable value or floor area is in general fairly equitable and has the advantage of being easily understood by the consumer.

A tariff having a primary charge of from 10 to 15 per cent per annum of the rateable value, with a secondary charge of ½d. per unit, is quite common in these days, and at that price electric cooking and heating are cheap and can compete easily with any of their rivals. A private house, making reasonable use of various appliances, can obtain electricity at an average price of 0·7d. per unit over the year for all supplies. In my view it is essential that the secondary charge should not be above ½d. and that the standing charge should be fixed as low as the finances of the undertaking will permit.

Efforts have been made to bring about some uniformity in domestic tariffs, and although the matter has been considered by two Committees appointed by the Electricity Commission there still seems to be no consensus of opinion as to which is the most suitable for general adoption. The 1925 Committee on Domestic Supplies of Electricity and Methods of Charge, and the 1929 Committee on Uniformity of Electricity Charges and Tariffs, both considered that the size-of-house or floor-area basis was the most suitable on which to fix the standing charge, but apparently the supporters of the rateable-value system have not found it necessary or desirable to make any change.

The McGowan Report on electricity distribution emphasizes the need for standardization of methods of charge as being an essential preliminary to any progress towards greater uniformity in actual charges. To this end the report recommends that the 2-part tariff which supply authorities should be required to offer should be based either on floor area or on rateable value. It is clear, therefore, that the rateable-value method, through its wide adoption by municipalities, has perforce been recognized by the McGowan Committee, and two methods are now left in the running if the recommendations are put into effect. I think, however, that in spite of the undoubted advantages of the rateable-value system (particularly its simplicity) the merging of undertakings covering different rating areas will accentuate the principal objection to this basis, namely the inequalities of assessments of similar premises, and this may be the deciding factor in favour of the floor-area basis. It will be interesting to see which method will ultimately prevail.

Allied to the tariff for electricity are the schemes for simple hire and hire-purchase of apparatus and wiring, to enable the consumer to obtain on easy terms the means with which to consume the cheap current.

Most undertakings to-day have some form of assisted wiring, and it is undeniable that the introduction of such schemes has resulted in a vast increase in the number of consumers. In many large cities and towns the percentage of houses connected is deplorably low, probably due to a great extent to the high proportion of artisan dwellings. The occupants of these dwellings work to a weekly budget and, in consequence, are unable or unwilling to put down in one amount what is to them a large sum for wiring the house. They can, however, readily find the few shillings per week to pay off the cost, and my own experience is that they think it well worth while.

In my own area an assisted wiring scheme was introduced 7 years ago. Since its inception upwards of 14 000 small dwellings have been wired, representing 35 per cent of our total domestic consumers and 27 per cent of the total houses in the area. Prior to the introduction of the scheme this field was practically untouched, and I am convinced that but for the scheme not 10 per cent of the 14 000 would have come on the mains.

As I previously mentioned, radio in the form of the H.T. eliminator or the " all-mains " set has been of great assistance in obtaining business in this quarter.

Various methods of collecting the price of the installation are in vogue, but personally I favour the prepayment meter, calibrated to collect the desired sum until the installation is paid for. The greatest advantage is that payment is in advance, and here again radio helps, as, even if the rent collector has to go away empty-handed, someone will be willing to find a penny to get the wireless going.

For the somewhat larger house a hire-purchase scheme with quarterly payments spread over 3 or 4 years is more suitable. This class of consumer is usually prepared to have a number of plug points installed in addition to lighting, if reasonably low prices are available. The way is then opened up for the wider use of electricity in the home.

The majority of undertakings have a scheme for simple hire of cookers, though some prefer to confine their activities to hire purchase. Within the last few years electric cookers have become more stable in design, or, to put it another way, they do not become out-of-date so rapidly as they did 5 or 6 years ago. In those days consumers were reluctant to commit themselves to an article which might become obsolete in a few years, but nowadays a purchaser can count upon getting a reasonable life out of his purchase.

It must be admitted, however, that undertakings having simple hire schemes are making far greater progress than those which have hire-purchase schemes only. Maintenance costs, which used to be very heavy, are now coming down to a reasonable figure, owing principally to improvements in the design of hot-plates and in a less degree to improvements in design of elements, switches, and internal wiring. I am afraid that a few years ago the finances of a large number of cooker hiring schemes would not bear too close an investigation, but I am satisfied that they are quite sound to-day.

Other good lines for simple hire are fires, irons, wash boilers, water heaters (including the immersion type, the circulator, and the thermal-storage type), but appliances which have a high first cost and consume very little energy, e.g. washing machines, vacuum sweepers, refrigerators, and the like, are more suitable for hire purchase or sale outright.

Having introduced an attractive tariff, complemented by appropriate schemes for simple hire and hire purchase, the next step is to provide showrooms for bringing the goods to the notice of the consumers. The supply undertaking's showroom should be devoted mainly to the exhibition and demonstration of the apparatus it offers for hire and hire purchase, as I have already outlined. Lighting fittings and small accessories are better left to others, although perhaps in some small towns the electrical showrooms may be the only convenient medium for display.

One should never lose sight of the fact that the function of the supply undertaking is to supply electricity, and that showrooms and sales schemes are merely a means to an end.

Most undertakings run periodical cooking and washing demonstrations in conjunction with their showrooms. In a compact town area these can be held at the showrooms, but with a rural or semi-urban area it is necessary to hold demonstrations in the larger townships or villages. My experience is that cookery demonstrations are a great attraction to the ladies and afford a good opportunity for bringing other apparatus to their notice. Quite a few undertakings have special demonstration vans fitted out which can be set up in country villages. The amount of apparatus that can be put out by loading up a van and hawking it from door to door is surprising.

One might think that such a method is undignified on the part of a municipal authority and that it classes the supply undertaking with hawkers and canvassers. I find, however, that, provided an official letter is sent a few days in advance saying that the van will call on a certain day, most consumers give a good reception to the salesmen and are genuinely interested in the apparatus they have to demonstrate.

In two villages where 900 consumers are connected, two canvassers with a demonstration van secured the following orders in 10 days:—

71 cookers.
20 immersion heaters.
27 irons.
12 other appliances.

Such a volume of business could certainly not have been obtained by merely sending out letters inviting the consumers to call at the showrooms. It cannot be denied that a vast amount of business is done by bringing directly to the notice of the public the goods one has to sell, and persuading the individual that a particular article is the one thing he cannot possibly do without. If the grid is to be loaded up, then we must adopt these methods in our industry.

The fitting-up of electrically-equipped exhibition houses on building estates in collaboration with builders, tradesmen, and the Press, is now a regular feature of many progressive supply authorities in their efforts to increase the domestic load. This method has the great advantage of showing visitors the various electric appliances in use under home conditions, and much business can be done when there are in attendance the right type of salesmen who are able to interest visitors and follow up inquiries.

In the matter of publicity I should like to pay a tribute to the good work which is being done by the British Electrical Development Association and the Electrical Association for Women in helping to foster the electrical idea, which is so necessary for the cultivation of the domestic load.

Having got our consumer electrically minded and well supplied with apparatus, then we must make sure of keeping him, and to ensure this the vital necessity is an efficient service department. Large monopolies, whether government, municipal, or company, have not a universal reputation for being prompt in service, but there is no reason why they should not give just as an efficient service as a business house in keen competition with its rivals. Without doubt, a consumer is vastly impressed by the appearance of a service man on a motor cycle or van within a few minutes of his telephone call to the depot. On the other hand, there is nothing more exasperating than lack of attention to a fault which may be a minor one but which causes major inconvenience.

Without entering into much detail, perhaps I might just touch on the question of distribution, as it is affected by the domestic load. I think that most supply engineers have realized that the capacity of mains which were usually put down 10 or 15 years ago will be quite inadequate to handle effectually the domestic load of the near future. A very moderate-sized house may require 20 kW of connected load or even more, and taking a street of 60 houses the connected load will be 1 200 kW. With a generous allowance for diversity it will be seen that the amount of copper required will be considerable.

Voltage regulation is most important. The fairly wide variations which are permissible for lighting cannot be tolerated on a heating and cooking supply. An oven which varies in performance owing to variation in voltage is an annoyance to a cook, and an electric fire with elements just a dull red is a poor advertisement for the supply authority.

If regulation troubles are to be avoided the radius of distribution will have to be quite small. It is not too easy to decide between laying down sufficient copper to take care of all eventualities, and the alternative of strengthening up the network as and when needed. On the one hand the undertaking may be overburdened with unremunerative capital, and on the other there is the additional expense if the extensions follow too quickly upon one another. It is obvious that a fairly extensive high-tension network will be required, and substations will have to be much more frequent though not necessarily of large capacity.

Some engineers have advocated the return to the old "house to house" system at 2 000 to 3 000 volts with transformers on the consumers' premises, but I do not think that the system will ever be re-introduced. Apart from the danger, there is the question of new connections and repairs, and it is certain that the consumers will never submit to the supply being interrupted while service connections are made.

Incidentally, electric clocks are the greatest tell-tales in the matter of short interruptions. One used to be able to shut an area down in the small hours without the fact being known to more than a few, but in these days attention is drawn to it in the morning by the electric clocks having stopped.

The growth of the domestic load has caused this question of continuity to become one of first importance, particularly in rural districts. High-tension switchgear and transformers must be shut down at times for cleaning and maintenance, and therefore it is desirable where possible to have an alternative feed on the low-tension side from an adjoining network area. In isolated areas occasional interruptions are unavoidable, and no matter how carefully chosen is the time for shutting down the supply, someone is bound to be affected even if it is merely some enthusiast listening to American programmes on his radio.

Pressure regulation has not been helped by the section of the Electricity Commissioners' Regulations dealing with the introduction of 3-phase supplies into consumers' premises. In a rural district one will find large houses at fairly long distances apart, and satisfactory pressure regulation cannot be obtained in such cases on one phase of a 3-phase 4-wire system. Static balancers and pressure boosters are coming into more general use as temporary expedients in rural districts as loads are increasing, but probably the most satisfactory solution is reasonable size of copper and plenty of transforming points.

I mentioned earlier in this Address that a suitable tariff was one of the essentials for building-up a domestic load, and I claimed that the majority of supply undertakings were now offering such a tariff. I venture to suggest, however, that the present grid tariff is not altogether helpful in enabling undertakings to offer low tariffs. Many engineers have expressed their fears of the effect of the heating load on their costs, and at least one undertaking has threatened to withdraw its cooker hire scheme in consequence of the effect of the maximum-demand charge on its finances.

The chairman of one of the large supply companies gave some startling figures as to the effect which the cold spell of last December had had upon their expenditure for maximum-demand charges.

In my own undertaking the maximum demand last December had increased by 3 477 kW, or 22 per cent, on the previous year. The bulk of this increase may be attributed to the cold spell coinciding with the heavy pre-Christmas load. A repetition of the great frost of 1929 would, I think, cause quite a stir throughout the country.

It may be argued that the revenue of the grid scheme has to cover the expenditure and it is not of great moment how it is obtained, but the tariff should be so framed that it does not discourage the development of any form of load. In my view the present grid tariff, basing, as it does, the maximum-demand charge for the whole year on one half-hour, will definitely hold back the full development of the domestic load.

I feel sure that if the grid tariff is continued in its present form, engineers will be driven to introducing vexatious restrictions on consumers' hours of supply, which is altogether contrary to the idea of service.

As I mentioned at the outset of my Address, the domestic business now represents the most fruitful field for the supply industry. The large increases in domestic consumptions which are being recorded year by year are ample evidence of this. But in spite of such large increases we are only too well aware that saturation point is still a very long way off. We have only to look at our " units sold per domestic consumer " to see how far short of the potential demand are our present sales.

In my own area the units sold for lighting and domestic purposes have increased in the last 3 years from 21 millions to 32 millions per annum, an increase of 50 per cent. While this may be regarded as quite good progress, I consider that we have only just touched the fringe of this market. Taking a very conservative estimate of the potential demand, the present output represents only about 20 per cent of the possible domestic sales in the area.

It is true that the present demand is the cream of the domestic load, quite a large proportion of it being the demand from newly-erected property, and that the real inroads into the domestic demand possible in the older houses have yet to be made. This will only be accomplished in a reasonable time by such methods as I have already outlined, which briefly may be summed up as:—

(*a*) The provision of a suitable and attractive domestic tariff.
(*b*) The provision of adequate simple hire and hire-purchase facilities.
(*c*) Prompt and efficient servicing of apparatus.
(*d*) Efficient sales and publicity methods.
(*e*) A helpful grid tariff.

Whatever re-arrangement of electricity distribution is made in the future, whether on the lines of the McGowan Report or otherwise, the fundamental conditions for the progress of the domestic load will remain the same.

NORTH-WESTERN CENTRE: CHAIRMAN'S ADDRESS

By G. L. PORTER, Member.

(ABSTRACT *of Address delivered at* MANCHESTER, *20th October*, 1936.)

Those of us who can look back to the comparatively early days of electricity supply are aware of many truths impressed upon us by comparatively bitter experience, and, indeed, there is something particularly convincing about knowledge gained from trial and error. As a great many of the early lessons have never found their way on to paper, I feel that the early development of a pioneer system of power supply, with special reference to some of the technical problems encountered, might be of sufficient interest to form the subject of an address of this nature.

When I first joined the undertaking in question—the Newcastle-on-Tyne Electric Supply Co., Ltd.—it had already embarked upon a system of 3-phase h.t. supply. Its original 2 000-volt single-phase lighting system from rope-driven Mordey alternators was still in use, although being rapidly changed over to 3-wire direct current. The supply to the latter had also just been changed over from steam-driven sets to motor-generators fed from the new 3-phase plant. The new power station itself also showed signs of rapid development, the original flywheel alternators driven by marine-type triple-expansion engines having already been supplemented by a Parsons turbo-alternator of the rotating-armature type with h.t. slip-rings under a glass cover, while a further turbo set with rotating field was on order. It will be seen that the whole undertaking was in an extremely interesting stage of development.

The nature of the area deserves some consideration as, of course, it had a profound effect upon the subsequent development of the system. Shipbuilding and coal-mining were the most important industries, and were accompanied not only by the engineering works ancillary to themselves but by others attracted to the district by cheap coal. It should be noticed that of the two fundamental industries the first is one in which electrification is easily justified, while in the second it is very difficult for a public supply undertaking to compete with private plant. It should further be noticed that from their very nature shipbuilding and coal-mining form rather a spread-out load.

One of the early developments almost peculiar to the area was the extensive utilization of waste heat, gas, and steam, particularly waste heat from coke ovens. This development was largely due to the fact that the modern type of by-product coke oven was introduced in this country at a time when the supply system in question was sufficiently developed to be in a position to absorb easily the output available whilst still having a fuel cost high enough to render waste heat units attractive. This development is of interest not so much from the economic aspect, but because of the problem introduced by the running of so many power stations in parallel. This will be referred to later.

Among the many technical problems that arose during the development of the system there were three of major importance—protection, communication, and regulation.

PROTECTION

A large power-supply system is essentially an h.t. network, and the problems that arise are very different from those of an l.t. network. This is due primarily to the fact that in the h.t. system duplicate supplies are generally required, and, secondarily, that the limit of loading is thermal instead of a question of voltage-drop. The branching tree layout which is common for l.t. work is therefore not generally suitable for high tension, as the provision of a duplicate circuit throughout is uneconomic in copper as compared with an interconnected network. The development of a system in the form of a large interconnected network fed from a number of power stations, some of which from their nature had to be run at something approaching constant load, soon raised in an acute form the question of protective gear. At that time the only gear available consisted of over-current and directional devices with inverse time characteristics. Even with modern over-current relays, the number which can be used satisfactorily in series is strictly limited, owing to the longer time settings becoming excessive, and even a simple radial system with a single power station can soon grow to a size beyond which something very different in the way of protective gear is necessary. Necessity is said to be the mother of invention, and in this case it gave birth to the first form of balanced protective gear known as "Merz–Price." This was followed after a few years by "Merz–Hunter" (split-conductor protection).

The use of protective gear has two aspects. Such gear may be installed merely to limit the amount of damage done to the faulty apparatus itself, in which case its value depends upon the value of the associated apparatus. On the other hand, it may be installed with the primary object of ensuring the maintenance of general supply by disconnecting from the system any fault which might endanger such continuity. In the latter case the value of the protective gear bears no relation to that of the associated apparatus, but depends on the value placed upon continuity of supply, and therefore upon the size of the system. A further difference is that in the first case the emphasis is necessarily on sensitivity, stability being of minor importance, whereas for the maintenance of supply complete stability is essential and sensitivity of lesser moment. Many initial difficulties had to be overcome during the development of these protective gears.

In a simple Merz–Price circuit, the minimum fault-setting allowable is the resultant of two quantities at right angles. One of these depends upon the characteristics of the protected feeder and on the ratio of capacitance to conductance of the pilot cable, while the other depends upon the iron circuit of the current transformer and the operating volt-amperes of the relay. No general improvement could be obtained unless both components could be reduced, and as limitation of space available in switchgear prevented much increase in the size of the current transformer, attention was naturally concentrated upon the relay and the pilot cable, resulting very quickly in the production of a much improved design of relay—the Fawssett–Parry. Direct improvement in the pilot cable was a much more difficult problem, a solution being eventually found in the Beard–Hunter screened pilot.

Split-conductor protection had also its initial troubles, and owing to the fundamental differences between the gears the previous work done in developing Merz–Price was of little assistance. Before the introduction of the split switch the current transformers had to act as reactance coils as well as current transformers and had to have a large cross-section of iron and many primary turns. It will be appreciated that in such a current transformer, when connected to a high-impedance relay, the rate of change of flux at reversal was so great that, although the calculated maximum r.m.s. value of the secondary voltage was under 200, the peak value was probably tens of thousands, so that the relay had to have reinforced end-turn insulation, such as is customary in power transformers. The development of a successful split switch was also not nearly so easy as it sounds, and it was also not realized at first that when a split switch breaks a large balanced current the parallel arcs do not extinguish simultaneously, and therefore a momentary out-of-balance, sufficient to operate a quick-acting relay, will exist. This means that if a split switch is equipped with overload tripping for system sectioning or other purpose, its operation is likely to bring out the other end or ends of the feeder, thus causing inconvenience and delay. As the addition of overload tripping to a split switch is very desirable in certain circumstances, an attempt was made to use delayed split-conductor relays, the delay being adjustable between 1 and 3 cycles (40-cycle system). The relays themselves were quite satisfactory, but their use had to be discontinued as it was found that when a fault occurred a delay of even 0·05 sec. introduced a definite risk of the insulation of the healthy "split" breaking down at a point adjacent to the fault on the other.

A third trouble was due to the inductive effect of return fault current in the lead sheath of telephone cables hung on overhead lines in an unsymmetrical position relative to the split conductors. The cure in this case is, of course, obvious.

The adoption of Merz–Price protection for transformers forced us to take notice of the magnetizing transient, a phenomenon which was, of course, well known but normally ignored. "Transient," by the way, was not at that time in the supply engineer's vocabulary, although the word "surge" had already become quite popular as an excuse for cable breakdowns.

In any system having all the feeders and transformers equipped with balanced protective gear, it is necessary to introduce a number of graded time-delay relays to limit the extent of the shut-down should a busbar fault occur or the switch on a faulty feeder or transformer fail to trip. The selection of a suitable arrangement of sectioning and sub-sectioning on a very large inter-connected system having many power stations with dissimilar characteristics is no easy matter, especially when the enormous majority of the substations are unattended. The following points have to be borne in mind:—

(*a*) The division of load between the power stations so that no station can become isolated with more load than it can deal with, particularly in the case of waste-heat stations which are constitutionally unable to deal with overloads.
(*b*) Facilities for re-synchronizing isolated sections.
(*c*) The placing of sectioning points where attendance for reclosing is permanently or quickly available.

COMMUNICATION

Means of immediate communication between power stations or substations and the control engineer are vital to a supply undertaking of any size, and the telephone system of such an undertaking is subject to the hazard of induced voltages to a far greater degree than any public telephone system. Further, the failure of a public telephone line is not likely to occur simultaneously with some abnormal demand for immediate communication, whereas on the supply system the very fault which has subjected the telephone circuits to excess voltages also renders immediate communication essential, and the usual form of protection—arresters and heat coils—is therefore quite unsuitable. When an arrester flashes over it puts one end of the line relay to earth, resulting in a breakdown between turns of the relay, and so putting the line out of commission.

A recent report gave the results of tests of inductive interference caused by earth currents on public telephone circuits. In the private system referred to, owing to the close proximity of telephone and line conductors the induction was produced directly by residual currents in the line, and there were three degrees of exposure:—

(*a*) Overhead lines with telephone cable suspended from a catenary wire.
(*b*) Underground cable (paper, lead-covered).
(*c*) Underground cable (lead-covered, wire-armoured).

The voltages induced per ampere-mile were roughly in the ratios of 5, 2, and 1, due to the progressively greater amount of shielding provided by the lead sheaths and armour, and the only serious trouble occurred on the overhead routes.

Reduction in the amount of residual current by increasing the value of the neutral earthing resistance defeated its own object, as it increased the liability that a line flashover due to fog particles would cause sufficient rise in the voltage to earth of the other two phases to produce a second flashover, so causing residual current to flow uncontrolled by the neutral earthing resistance. The hazard to telephone terminal gear and its users could have been avoided by sufficient insulation of both from earth, but, unfortunately, the induced voltages were sufficient to cause breakdown of the telephone cables and actual limitation of the voltage became essential. The air-space cable used had, of course, a much lower breakdown value between pairs than to earth, and the breakdowns were therefore almost always initially between pairs. Had these pairs all terminated at the same place at each end, no voltage between pairs would have appeared, only voltage to earth. Unfortunately, owing to the fact that the great majority of the substations were unattended, it was essential that each pair should be connected as far as possible to a different substation, with the result that considerable voltages between pairs were produced. The solution of the problem was found to be the so-called " drainage coil," which is simply a single-phase 3-wire static balancer on a small scale, its outer terminals being connected to a telephone pair and its mid-point earthed. It had, of course, to be carefully designed and made so as to get sufficiently good balance between the half windings. It is rather interesting that the limiting features of the design were not connected with the effect on speech—their presence rather tended to improve the latter. The sole difficulty was to obtain a sufficient impedance across line terminals at the magneto ringing frequency, while keeping the resistance from line terminal to mid-point sufficiently low. Previous to this development drainage coils—as can be seen from their name—had only been used for dealing with electrostatic induction in bare-wire telephone circuits.

Although it is hardly connected with my subject, I should like here to make a reference to the question of induced voltage in a conductor when a metal sheath surrounding it is carrying current. This makes a very good test of any method of visualizing electromagnetic effects, seeing that no method is of much use to a student unless he is enabled by its help to see at once how it is possible for a voltage to be induced in a conductor surrounded by a cylindrical conductor carrying alternating current, when it can be proved that at all points inside the cylinder the flux has at all times zero value.

During the war a 20-kV split-conductor overhead extension was put in service some months before the duplicate line which included the telephone connection could be completed. The absence of means of communication proved so undesirable that an experiment was made in superimposing telephonic currents in the h.t. line, using the two splits of one phase as out and return telephone conductors. It was found that the reactance-type current transformers had a sufficient number of turns to make telephony quite possible. A condenser was used at each end to block any 50-cycle component due to unbalance in the line, and this condenser, of course, made ordinary magneto ringing impossible, a rather shrill buzzer having to be substituted. The condenser served the additional purpose of preventing any fault on the telephone circuit from short-circuiting the protective gear and rendering it inoperative.

REGULATION

At the commencement of h.t. power distribution, the charge engineer at the main power station was, of course, the system control engineer, but before long it was found necessary to separate these duties. In addition to the telephone and the system diagram which showed the position of all switches and isolators, summation instruments showing the voltage and load on each of the two main coal-fired stations were installed. There was also a synchroscope permanently connected between these stations. To give an indication of the total kilowatts of load on a station at a point approximately 10 miles away, through 20-lb. telephone conductors, was rather an achievement in those days, and was due to the initiative of Mr. E. Fawssett in developing a suggestion of Lincoln's into practical apparatus.

One important feature of the development of the system control was the introduction of the " permit-to-work card." The original card was made out by the district engineer after receiving permission to do so from the control engineer. It clearly defined the apparatus upon which the work was to be done, and before it was handed to the man in charge of the work a duplicate card was filled in by the control engineer and retained in the control room until cancelled. Each control engineer at the commencement of his shift looked through the copies of cards in force, and so learnt what gear was actually being worked upon. Such gear could not be made alive until the card was cancelled, which was done by the man in charge of the work signing a declaration that all his men were clear and understood that the gear was no longer safe to be worked on. This scheme worked admirably.

In any system having several power stations, an important part of the control engineer's duties consists of load-dispatching, for which a daily programme is necessary. What might be called the skeleton of the programme is worked out by the technical staff from considerations of thermal efficiency, transmission losses, and system stability, and the details are then filled in to suit the day-to-day conditions in the various stations. It must not be overlooked that on a large system protective gear and load-dispatching are intimately related, and, as it is not feasible to alter the sectioning of the system hour by hour to suit the relative amounts of plant running in the various stations, it is quite likely that considerations of system sectioning will dictate the minimum amount of plant to be run in the less efficient station or stations. The chief problem is not really a technical one, but consists of the usual difficulty in placing a cash value upon continuity of supply.

When real emergencies arise it adds greatly to the rapidity with which the control engineer can size up the situation and decide upon the best course to follow, if he is familiar with the station at which the trouble has occurred. The control engineers should therefore be given facilities for gaining the necessary knowledge, and this again is helped if substation layouts are standardized as far as possible.

The running of up to 15 power stations in parallel introduced no special difficulty beyond those mentioned previously in connection with system sectioning. The undesirable reduction in synchronizing torque caused by excessive resistance in an interconnector was shown very clearly when the local systems on the Tyne and Tees were first interconnected by a single, long, underground cable. The natural period of swing between the two systems, owing to the low value of synchronizing torque, was sufficiently long to approach the frequency of the gust admission of steam to two of the early turbines, with the result that at times when either of these machines was running quite an unpleasant oscillation could be built up. This trouble was removed by modifying the frequency of admission to the machines concerned. The use of so much waste heat naturally decreased the load factor on the coal-fired stations, reducing to some extent their thermal efficiency and making regulation of all kinds more difficult.

In an h.t. power-supply system, as distinct from one giving supply ultimately to domestic consumers, it is not economic to distribute at such a voltage that voltage-drop can be serious. The limit of feeder loading is therefore purely thermal, and voltage regulation as such does not arise. This does not mean that the type of apparatus used for voltage regulation is not required. The reason is that when one main feeder of an interconnected network is out of commission for any reason its load will not be shared equally by the other feeders, and if nothing is done to correct this inequality every feeder must be large enough to meet that emergency condition which gives it the greatest increase in load, and the total spare copper in the network may, in consequence, be excessive. In many cases the provision of regulators for controlling the feeder loads of such a network may be cheaper than the provision of sufficient spare feeder capacity, and at the same time they can be usefully employed in improving voltage conditions on the network. In the system under consideration, it was soon found that the provision of means for controlling the distribution of current in the main feeders would increase the kVA that could be transmitted to such an extent as to represent a considerable reduction in the capital cost per kVA. Voltage regulation in the main 20-kV feeders therefore became a standard part of their equipment. At a later date when the 20-kV network had to be reinforced by 66-kV lines, the much higher ratio of reactance to resistance of the latter, due largely to the presence of step-down as well as step-up transformers, would have resulted in a large difference in power factor between the 66-kV and the 20-kV circuits, with a consequent reduction in the useful kVA capacity. Calculation showed that, for conditions likely to arise in this country, separate in-phase and right-angle boosters are quite unnecessary, and a single booster at a fixed and easily obtainable angle is all that is required. It will generally be found that for an overhead line directly in parallel with a cable a boost in the former at 30° leading is suitable, while in a case similar to that just mentioned a boost at 60° leading in the high-voltage circuit is satisfactory.

Four of the earliest regulators used on this system were of the single-unit 3-phase induction type, and as the system became more closely interconnected these had to be strictly confined to circuits in which the angular displacement produced by that type of regulator could not cause serious circulating currents. Further, as the system short-circuit kVA increased, the keying of the rotors to the shafts of these induction regulators had to be considerably strengthened, the torque being sufficient to shear the original keys.

The first tap-changing regulators, although installed about 28 years ago, gave on the whole extremely good service in spite of the fact that their switchgear had to deal with 9 000 kVA at 20 kV. They were of the type in which the switchgear is housed in a tank completely separated from that containing the windings, and all the tappings had therefore to be brought out through bushings. The makers had apparently not realized the transients to which these tappings would be exposed, and the latter were insufficiently insulated from each other. Until this was rectified it was actually necessary to put any regulator in its no-boost position before carrying out any switching in its immediate neighbourhood. Some trouble due to the breakage of operating springs was also experienced. These springs were used to prevent the gear stopping between steps, a requirement rendered necessary by the use of resistance bridging between steps instead of the modern continuously-rated reactance.

While these developments were occurring on the h.t. system progress was also being made in l.t. distribution. The first networks were direct current and consisted in many cases of vulcanized-bitumen cables either multicore or single. Most of the d.c. networks have now been changed over to alternating current, partly owing to single-core vulcanized-bitumen cables having proved unsuitable for d.c. use, and partly for economic reasons. One of the first change-overs was in a rapidly developing residential area at the coast, and the 3-phase system was —one might say—automatically adopted. Before long, however, the undesirability of connecting a 3-core cable to two phases and neutral of a 3-phase supply became obvious, and the network was converted to 3-wire single-phase working, which system was generally used for later change-overs.

It must be appreciated that the arrangement of a network laid out originally for d.c. supply is essentially different from one intended for alternating current. Converting plant, together with the capitalized cost of attendance, represents a considerable expenditure, but at the same time means for regulation of the d.c. busbar pressure are inherent in the nature of the plant. It is therefore customary to use direct feeders from the substation to feeding points in the network, the substation busbar pressure being raised to allow for the voltage-drop in the feeders. When such a network is changed over to alternating current provision of means of automatic voltage regulation becomes, of course, essential. In the case of the normal a.c. substation where the outgoing cables are distributors, the advantages of automatic voltage regulation are not so obvious and to some extent depend on local circumstances. There are two typical cases. In the first case the regulation of the network is generally satisfactory, but, owing to unsymmetrical development, the voltage-drop in one part of the network is becoming excessive. Improvement can be obtained either by an h.t. extension and new substation, or by means of a voltage regulator. Even if the anticipated growth of load is such that a new substation will eventually be required, the use of a regulator may easily be justified, as not only will it allow of the postponement of the capital expenditure on the h.t. extension, but being a standard piece of apparatus it can be used in a similar manner on some other part of the system when liberated by the provision of the new substation. In other words, such a regulator is a portable means of saving capital charges.

The other typical case is where the h.t. supply to a substation is subject to voltage variation. In such cases sufficient improvement may sometimes be obtained by means of voltage regulation in the h.t. system, but it must not be forgotten that the nearer a regulator is to the consumer, the more effective it is. Most engineers agree that a voltage variation of more than ± 4 per cent is not really satisfactory, and that figure means that if the substation busbar voltage can be maintained at + 4 per cent at maximum load, then 8 per cent drop is allowable to the farthest consumer. If, however, the h.t. system is subject to a drop of 4 per cent, only half the previous drop is allowable in the l.t. mains, and either much larger and more costly cables, or many more substations, will be required. The cost of either of these alternatives will be greater than the cost of providing on-load tap-changing or other means of regulation at the substation. It should also be mentioned that some authorities are of the opinion that the additional revenue gained as a result of the higher average voltage at consumers' terminals will itself pay the capital charges on the regulating apparatus.

Nearly 20 years ago the development of l.t. loads together with the change-over of networks from direct to alternating current made it obvious that a great deal of automatic regulating apparatus would soon be necessary, and also that the apparatus on the market at the time hardly met the requirements. We had to institute an extensive campaign for better and cheaper regulators, and while doing so originated the use of the so-called "protective reactor" which is so popular nowadays. I believe that the seed sown at that time had more than a little to do with the amazing development in new and better forms of regulator and on-load tap-changing gear which has occurred in recent years.

Before concluding, I would mention two other matters of interest. First with regard to neutral earthing. It is sometimes stated that the maximum value of earthing resistance allowable is determined by the fault current necessary to operate the protective gear, and this is probably correct for a wholly underground system. Where, however, overhead lines are used, a much lower value of resistance is desirable, for the following reason. When fog or other cause reduces the flashover voltage to a dangerously low value, it is essential that the neutral should be sufficiently anchored to earth potential, as otherwise a flashover on one phase will be likely to produce a flashover on one or both of the others—possibly on the duplicate line to that on which the original fault occurred.

Lastly, I would mention a case of oscillating neutral which occurred as a result of a short length of 66-kV cable being made alive through a bank of single-phase star/star transformers. The transformers were installed as step-down units with both neutrals isolated, the 66-kV neutral being earthed on the step-up delta/star bank at the other end of the line. The overhead line work was incomplete, and it was thought desirable to make the completed length of terminal cable alive, seeing that belted cable for such a high voltage was already rather under suspicion. The neutral of the 66-kV side of the transformer bank was earthed, and the switch on the 20-kV side closed. The district engineer, having had no experience of transformers larger than one-tenth of the size of the bank in question, did not realize that the loud noise emanating from the latter was evidence of something being wrong, and therefore left the job alive for several hours. Luckily, when he returned to the substation it was sufficiently dark for the corona on the 66-kV connections to be noticeable. Although there was no breakdown, the cable concerned was soon afterwards replaced owing to the failure of similar belted cable elsewhere, but the transformers are still in commission and do not seem to have suffered. One interesting feature of the occurrence is that it was clearly evident from the corona discharge that the phase of the oscillation was changing steadily but comparatively slowly, so that the three line conductors experienced maximum voltage to earth in rotation, the complete cycle occupying about 2 seconds.

In conclusion I should like to express my thanks to Mr. H. A. Couves of the North-Eastern Electric Supply Co. for his kind permission to make these references to the development of the large undertaking on the North-East coast.

NORTH-EASTERN CENTRE: CHAIRMAN'S ADDRESS

By D. MAXWELL BUIST, Member.

"THE ENGINEER AND THE FUTURE OF ELECTRICITY"

(*Address delivered at* NEWCASTLE, *26th October*, 1936.)

POST-WAR WORLD CONDITIONS

In the years immediately following the war, all nations appeared to have as their objective a return as speedily as possible to pre-war conditions and relations. Such an object implied an underlying philosophy that the effect of the war upon human progress and the world's business was purely transient, and might therefore be expected to die out gradually after the style of a damped oscillation. But that philosophy has been more and more discredited as the years have passed. It is still too early for the oscillograph of history to yield a complete analysis of the effects of the war, but sufficient time has elapsed for the record to distinguish between the more or less transient effects and those changes in the current of human affairs which are proving to be more permanent. Looking back over the years, it is clear that the war has resulted in a definite, far-reaching, and probably permanent change in the economic policy of all the principal countries of the world and, consequently, in their internal organization. Before the War, international trade was, in general, conducted in an expanding international market on a basis of more or less friendly rivalry between individual industrial concerns in the chief competing countries. To-day, international trade has been drawn into the arena of international politics. For four years the belligerent countries bent their whole energies to the task of substituting destruction for production. In the endeavour to escape their share of the economic consequences, nation after nation has since abandoned traditional policies in favour of import restrictions, currency manipulation, and intensified competition, for a steadily diminishing international trade. Shrinking world trade is the inevitable corollary of the gospel of national self-sufficiency which is now emerging as the avowed policy of some of the most important countries in the world.

This change in international outlook and objective has naturally been accompanied by profound changes in the structure of industry. Individualistic commercial enterprise in each of the principal producing industries had to be forged into one combined effective spear-head in the national attack; hence the processes of association, combination, and rationalization, which have been such a marked feature of post-war industrial reorganization. It is still too early to determine whether these changes are really permanent. The pessimist points to the rapidly accelerating deterioration in international relationships, and declares that economic nationalism is unstable, and it is economic war and must result sooner or later in physical war; the optimist claims that as the world emerges from the post-war slough of despond international tension will relax. What the outcome will be no one can predict, but my purpose in directing your attention to the general situation in world affairs is solely that we may consider its effects upon our own country and our own industry.

INDUSTRIAL RECONSTRUCTION AND THE ENGINEER

In no country has the effect of the post-war re-orientation of industry been felt more widely than in Britain. One, and perhaps the most important, of the inevitable consequences of the new philosophy of economic nationalism has been the abolition of the isolation era in industry which existed prior to the war. The searching test of war revealed the restrictive effects of that era which were nowhere more evident than in the field of public utilities. Consequently, it was not surprising that the lessons learnt so painfully during the war were applied during the industrial reconstruction which followed. In our own industry their application resulted in the 1926 Act, which provided the industry with its first successful example of co-ordinated policy and with a foundation in the grid system, upon which to build a new era of ordered progress. The 1926 Act, which fundamentally altered not only the constitution of the supply industry but also the outlook of the engineers who serve it, is typical of the changing outlook which has been forced upon all branches of the engineering profession. During the last decade, engineers have devoted more attention than ever before to problems relating to the economic development and co-ordination of industry.

Progress is inherently a gradual process, however, and not the least of its obstacles, paradoxically enough, is man himself. Steeped as we are in tradition, a radical change in our outlook is neither easy nor quick, and consequently many of the problems arising from, or rather revealed by, the war and the subsequent industrial reorganization are still with us and are increasing in number and complexity. I do not, of course, give to progress merely the meaning of progression towards higher proficiency of processes, but rather the broader meaning of the upward march of improvement in human and national welfare. Too often in the past, engineers as a body have concentrated upon the former to the exclusion of the latter, too often they have buried their heads in the countless sands of technical problems with a complete disregard for the major and more vital problems of national policy, of which the technical problems are but an inherent corollary. The policy of a nation, or of an industry, is not dictated by technical difficulties but by economics, and it is of vital importance, therefore, that engineers should, without necessarily becoming masters of the technique of the economist, learn to appreciate in what way the teachings of economic science can help in the solution of their own problems.

To a large extent the engineer regards economics with suspicion, partly as a result of the existing system of technical education, but probably more as a result of the fact that engineering is an exact science, and, consequently, unless the economic problems which he encounters are susceptible of analysis with the same mathematical precision as engineering problems, there is an innate tendency for him to regard the study of economics and the employment of statistical methods as a mere waste of time. The literal definition of economics is "the science of household management." Household management! Could any definition be more aptly simple ? In other words, it means the study of efficiency in the management of the household, our own household, other people's households, the household of the community, of industry, and of the nation. It is the study of how people should live, of the ways and means of living, of the art of living. It is the study for which the engineer is eminently fitted, not only because of his methodical mentality but more because the commodity he distributes permeates every sphere of social and industrial activity and so brings him into intimate contact with the immense problems of human welfare.

In our own particular industry another obstacle to progress, or rather to acceleration of progress, apart from man's innate conservatism or objection to change, is the widespread feeling of uneasiness as to what is going to happen next, not only in our own industry but in world affairs in general. The past record of legislative endeavour in electrical matters is so lamentable that we are sceptical of any real success in any future endeavour to remove the onerous burdens of the early Acts. Electricity, however, marches on, and is now established as such an essential part of our industrial and social fabric that the time must inevitably come when public opinion will force the removal of the restrictions which still hamper progress and will demand the changes so necessary for success in the continued co-ordination of our industry. Production is now so effectively organized that it reveals more glaringly than ever the weaknesses in other parts of the structure of the whole supply industry, weaknesses of whose existence we have always been uneasily aware. They must and can only be remedied by applying the same broad vision, the same boldness of action, and the same co-ordinative effort, which post-war experience has taught us to apply with such success to other defects in our structure.

OWNERSHIP AND ITS EFFECT UPON RATIONALIZATION

The alarming rate at which the world's natural fuel resources are decreasing is causing every nation in the world to devote increasing and urgent attention to the economic utilization of their power resources and to the co-ordination of the utilities employing them. The impact of electricity upon every facet of modern national and human conditions is so widespread in its ramifications that its problems are paramount in the conservation question. The papers read at the recent World Power Conference reveal, as never before, the growing importance and uneasy urgency attached to these problems by every nation in the world. The real and major issues involved in these problems, and particularly the ethical aspects thereof, the questions of rationalization, co-ordination, and the inculcation of a wider social outlook on the part of engineers, were, unfortunately, rather obscured by the eminence given to the vexed question of public versus private control, especially in the United States, and to the role of governments in the co-ordination of supply systems. The natural development of the electricity industry, with consequent growth in the number of undertakings, the results of experiments in co-ordination in various countries, the increasing interest of governments and of the general public in electricity supply, the somewhat tardy realization by the electrical engineer himself of his true function in the social fabric, together with many other factors, have all contributed towards reopening in every country the question of ownership, concerning which there was so much controversy in this country in the early part of this century. The emphasis placed upon this matter at the Conference seems to indicate that the controversy upon this legacy of mismanaged history is entering the final stage, and that there is an earnest desire by the partisans to effect some sort of settlement as soon as possible. This desire is clearly indicated by the growing realization among industrialists that really complete rationalization in any industry is impracticable under conditions of divergent interest in ownership, and the increasing political appreciation of the fact that no country can hope to retain its position as a world economic power against the competition of nations richer in natural resources without eliminating all economic and social waste. The latter in the all-pervading field of electricity connotes consolidation of interests, unification of policy and planning, rationalization—call it what you will—and, since rationalization in any industry involves some realignment of public and private rights in control, it is obvious that at this stage a fusion of interests in some degree, whilst not necessarily a complete and permanent solution of this problem, will contribute materially to that harmonious unification of effort in the industry so essential to its future policy.

It is interesting to note the trend throughout the world towards what our American cousins have termed "integration" of power supply systems. Integration, a term well-known to the mathematician and engineer, is happily applied to the process of synthesis or building-up of the scattered units which are the legacy of early development, into a unified electricity supply industry. Complete integration is the ideal to be aimed for, but the degree of possible attainment of that ideal differs in every country owing to the widely differing conditions. In all countries there is difference of opinion upon the question of ownership, in some more so than others, and in most countries experimental compromises, suitable to the conditions, are being tried. The establishment of the Central Electricity Board in Great Britain, of the Tennessee Valley Authority in the United States, of the Electricity Supply Boards in Ireland, of the Electricity Supply Commissions in Africa and Australia, of the Swedish Government's 2 000-mile coast network, and government intervention, although without a clearly defined policy, in Germany, France, and Hungary, all indicate the universal movement towards some degree of integration. Integration proceeds in stages, however, and there is so much more that the engineer can do in this direction that it seems a pity, although inevitable, that these very developments themselves should at this stage re-introduce the subject of ownership, because there is a danger that the complexities of this one aspect may obscure the rational objective implied by integration, unless the industry clearly appreciates that other aspects can, within certain limits, be dealt with collaterally and independently, until the process of integration has reached a state when further progress is impossible without unified ownership and control. Whilst the British plan, therefore, may not be generally adaptable to certain other countries, because of different conditions, there is no doubt that the universal lesson it taught was that a certain measure of integration in sections of the industry could be achieved independently of a permanent solution of the problems associated with ownership. That this lesson is being appreciated is revealed by the foregoing developments which have taken place in other countries within the last decade.

THE TRUE FUNCTION OF THE ENGINEER

The economic theory governing the commercial aspects of electricity supply to-day is that enunciated in two papers by Dr. John Hopkinson and Mr. Arthur Wright, as far back as 1892. It is, however, only within the past few years that electrical engineers have begun to concentrate upon commercial developments with as vital an interest as they have displayed in the technical developments which have taken place during the 44 years since those papers were written. This new orientation is largely due to the 1926 Act, which gave the majority of undertakings freedom from the time-absorbing responsibilities of production, with the result that a large proportion of the attention hitherto devoted to production is now being directed towards commercial development.

In other industries somewhat analogous changes have taken place, and the period of transition from what has hitherto been an intensive outlook on technical efficiency of production to what is now an extensive outlook on policy is an opportune time for engineers to pause and give serious consideration to the more exact definition of their future policy and its objective. They must ask themselves whether, in the future development of their respective industries, they are going to continue in the traditions of the isolationist period, when adequate return upon capital was the primary incentive influencing all decisions, and when, consequently, the welfare of the community was only incidentally looked after through the operating conditions of competitive development, or whether they are in future to take their proper place in the social fabric and realize their responsibilities as administrators of essential public services, in the operation of which the effect of every decision they make must be measured in terms of the welfare of the community they serve. As human beings rightly interested in the welfare of their fellow beings and, therefore, of their country, there can only be one answer to this question, but if any further incentive is necessary to hasten this answer then a study of the conditions in the principal European countries will serve to reveal the persuasive interest which governments themselves are now displaying in the proper function of utilities in relation to the interests of the community.

Engineers must therefore, without delay, formulate their policy in conformity with the trend of opinion, and with a clearly defined policy dictating their future activities they can then proceed with the orderly planning of these activities. This wider outlook will disclose economic and social problems which would otherwise have remained hidden, and the solution of which will ultimately result in the long overdue recognition of the true status of the engineer, that of a very essential and important component in the social fabric.

PLANNING FOR ECONOMIC DEVELOPMENT

The plans to attack this wider objective will be determined by the problems behind which the objective is entrenched, and therefore it is essential to ascertain whether or not there is sufficient information available regarding these problems to enable engineers to judge, before launching their plan of campaign, that they are following the best and most direct route towards the achievement of their policy. That information must be such as to enable them to gauge beforehand the result of any decision they make. They must be in intimate contact with the social and economic conditions of potential markets, and will have to interest themselves more than ever in such social problems as slum clearance, new housing conditions, town planning, and so on. In the electricity supply industry, for example, all possible information must be available with regard to:—

(1) Purchasing power of the market, i.e. potential load in different classes of consumers, percentage of possible and of actual attainment, and reasons for success or failure.

(2) The incidence of class loads, i.e. diversity that may be expected for given types of load under given conditions, e.g. cooker load, water heating, space heating, related to tariffs and type of consumers.

(3) Elasticity of demand in various classes of consumers, i.e. energy used and revenue received, related to type of consumer, tariffs, apparatus and provision for assisted wiring, hire and hire-purchase appliances.

(4) The pooled experience of the industry with regard to certain commercial practices such as assisted wiring schemes, the relative merits of hire-purchase schemes versus hire or sale, and the use of prepayment meters, etc.

(5) Economic limits in pricing apparatus for hire and hire-purchase, i.e. depreciation, interest, and maintenance, properly chargeable related to the total net effect on an undertaking's load and costs, in view of diversity and increased consumption.

With the problems set out before them engineers must have the means of obtaining such information as will enable them to measure the magnitude of the problems, to appreciate clearly the difficulties before them, and to enable them to decide quickly upon a course of action.

STATISTICAL SERVICE

Such facilities can only be provided by the establishment of a central organization for the collection and pooling of adequate and, above all, accurate statistical information to replace the present more or less voluntary system of haphazard collection characteristic of most industries. In our own case, existing statistics still have a distinct bias towards generation and fail to provide a proper basis for comparative analysis for the purpose of commercial development. The time-lag before such statistics as are collected are available renders them more historically interesting than useful. There are too many "sources" of statistics, none of which seems to provide exactly the information required and no two of which are strictly comparable. Too many different bases of comparison are employed and too many assumptions have to be made. All this confusion where accuracy should exist has resulted in the present chaos of individual inquiries, with their accompanying questionnaires, forms and schedules, criss-crossing between individuals, undertakings, associations, institutions, and the Press. The only common-sense solution, therefore, is the establishment of a common pool of statistics directed by an organization representative of every branch of the industry. The primary functions of this organization would be to study the purposes for which current statistical data would prove most valuable and the form in which necessary records might be most effectively kept by undertakings and summarized for the industry. Upon any such organization should be represented:—

(*a*) Economic training—to consider problems associated with costs and standards of performance.

(*b*) Statistical training—to eliminate all but essential data and to analyse such data properly and concisely.

(*c*) Technical training—to ensure that the investigations are correlated to technical developments.

(*d*) Practical experience—to assure the practicability of obtaining and keeping the records required, to organize methods of collection and release, and to advise upon practical aspects of the work.

Intelligent development of an area is entirely dependent upon a proper and thorough knowledge of the economic structure of that area, and the part of electricity in that structure. The central pool should therefore operate through area centres, into which would be fed systematically all information relative to activities in the industrial and domestic fields, housing and slum clearance developments, new industries and trading estates, potentialities regarding existing private plants, and so on, and from which would be issued periodical summaries and surveys of the position in the various spheres, with conclusions drawn therefrom, and information as to what is being done in other areas. The function of the organization would simply be to collate and analyse statistics and would not extend to making recommendations or proposals for the solution of any problem. It is not suggested for one moment that the organization should enter the field of publicity; that is rightfully the domain of the British Electrical Development Association. Neither is it suggested that it should enter the technical field, although there is no reason why it should not, but at any rate for the present it should confine its activities to the analysis of data regarding the problems of commercial development. To be successful, the requirements of such an organization should be met without demur, should not be regarded as optional and, above all, should receive the active support and co-operation not only of the Electricity Commission but also of every association in the supply industry. It is perhaps even more essential that engineers themselves should have a proper understanding of the data required and their purpose, should learn to depend upon prompt and accurate information, and, finally, should appreciate that statistics are not merely empty figures but are the tools with which to hew the way to economic stability in the industry with the minimum of wasted effort. Statistics are no substitute for judgment, but the weapon by which judgment is saved from the bias of ignorance or personal prejudice. To attempt intelligent development without statistics is futile; to attempt it with inaccurate statistics is puerile.

THE TECHNICAL FUTURE OF ELECTRICITY

Much of the industry's activities in the pursuit of its new policy will be directed towards the elimination of existing waste in its various branches, by improvements in production, distribution, and application. Acceleration of development in existing uses of electricity, coupled with the discovery of new applications, will increase the size of the wheel of supply and demand, and to keep this ever-growing wheel revolving at the same or probably a greater rate of progress will require greater efforts of human driving force and will involve technical problems of ever-increasing magnitude to maintain the structure and strength of the wheel. Progress in the pursuit of any policy, however, is measured by the success with which these technical difficulties are overcome. No better example of this exists in our industry to-day than the British grid system, the policy of which gave rise to technical problems which had never before been encountered by British engineers but which they successfully solved.

There are always with us, however, those who reflect complacently upon the past, who cannot see any hope for further improvements in the future, who consider that we have reached a position of static balance and who ask "What more is there to do? What more do we need?" Possibly nothing more, as far as our present needs are concerned, but the wheel of progress must and will march on at an ever-increasing pace, and human endeavour must ever remain at its hub to keep it turning, and above all to guide it in the path of human welfare with the minimum of wasted effort.

The present generation regards with pity the conditions of living and of transport in the past, but future generations will regard our conditions with equal pity. Many of us can recall a world without cars, aeroplanes, cinemas, wireless, telephones, gramophones, X-rays, and so on, and it seemed just as complete then as now. Think of the change that has taken place within the last half-century, due to electricity. This generation accepts, as commonplace, train speeds of 100 m.p.h., car speeds of 300 m.p.h., and aeroplane speeds of 400 m.p.h., and foreshadows, as natural, even higher speeds, but all these developments will pale into insignificance compared with the Wellsian developments of the next half-century. They will take time because of the incubation period between invention and application engendered by man's inertia to change, which in the past absorbed a quarter of a century between Watt's invention of the steam engine and Stephenson's application of it to locomotion, and nearly the same period between the discovery of wireless in 1897 and the introduction of broadcasting. Discovery after discovery has so bombarded human intelligence in the last century that we are becoming less surprised at anything and merely murmur " What next ?" Consequently, in looking ahead it is safer to predict what can happen than what cannot.

What, then, will emerge next from the important researches being conducted in the world's laboratories? In the realm of pure science, the investigation into the nature of matter has so far resulted in one of man's fondest dreams, that of transmutation of the elements, being realized to the extent that about half respond to treatment, in the course of which changes, radio-activities exceeding that of radium have been discovered. These radiations may yet replace X-rays in radiography, or radium in the treatment of disease, may be employed in the formation of new compounds by chemical processes, and may even provide us with more efficient sources of light than our present incandescent methods with their paltry 3 per cent efficiency. It may sound fantastic to expect from one pound of matter sufficient atomic energy to propel the " Queen Mary " once round the world, but it is not the law of conservation of energy which says it is fantastic; it is the fact that we are still a long way from discovering an efficient and practicable means of conversion.

In the realm of applied science, however, we are much nearer what we can reasonably expect within our present generation, for innumerable researches are being conducted in many different fields, from any of which at any moment may be announced startling developments. The greater and comparatively new field of electronics has developed by leaps and bounds since the discovery of X-rays. It has provided us with wireless communication and now television. It is playing an increasingly important part in the heavy industries, in supplying devices for inspection of materials, automatic machine control, safety precautions, and so on. Yet further discoveries therein will give us perfect broadcast reception free from interference, will provide us with a television service equal to our present-day wireless service, and will even have an important effect upon the control of power transmission and transformation.

The possibilities of electricity in countless other fields are limitless. It will yet be employed in the agricultural field for more purposes than mere mechanization. By some means of radiation and light treatment it will purify seeds, eliminate weeds, improve the soil, and destroy insect pests. It will yet be adapted to the hitherto untouched fields of water-purifying and air-conditioning in homes and factories, providing the community in crowded cities with the purity of mountain streams and the healthy atmosphere of seaside resorts. It will yet play an even more important part in biology, in the better understanding of the human body, in combating ailments like colds and influenza, which cost nations millions of pounds, in overcoming the multitude of diseases to which we are liable, and in providing the health-giving rays of sunlight in all climes and climates.

In industry, in the study of materials, important developments are taking place in the production of new alloys in accurately controlled electric furnaces, some of these being magnetic alloys with entirely new characteristics which will revolutionize electrical plant design, just as new methods of electric welding and developments in plastics are doing.

In transport little progress has been made as yet with electrical propulsion, but some day there may be such developments in the field of electricity storage that the electric motor will supersede the petrol engine. Meanwhile, the rapidly approaching exhaustion of the world's natural supplies of petroleum, which, it has been estimated by Sir John Cadman, will take place in less than 20 years, will give an impetus to development of the potentialities of electricity in the field of transport.

Discoveries in insulation research may yet give us alternators of still higher voltages, cables for the highest transmission voltages employed, which, coupled with probable advances in means of rectification, may some day altogether cause us to uproot our conceptions of present-day systems of generation and transmission.

In power generation itself, progress over the last 15 years can be gauged by the fact that about five times the electricity is produced with only slightly over twice the amount of coal—roughly a saving of over £12 million per annum on present prices. This means that thermal efficiency has been more than doubled, but this, although in itself is a very creditable achievement, should simply be regarded as indicating what engineering effort can do if only properly directed. Can anyone believe that engineers will be content with the attainment of 25 per cent efficiency in coal-cum-electricity conversion, and that there is no hope of finding more vastly efficient methods? The very fact that we have gone as far as we economically can go in the improvement of the existing heat cycle should result in greater concentration of our activities in the search for new methods. The vital and compelling urgency for giving undivided attention to the conservation of our fuel resources, the rapid increase in consumption of existing applications of electricity, the future policy of the engineer, and the birth of a new era of ordered planning in the industry, all constitute a barrage in the attack upon waste at its most prolific source, that of inefficiency of production, which, with the passage of time, can have but one effect. Is it inconceivable, therefore, that large-scale hydrogenation or other processing of coal, instead of the present wasteful burning under boilers, will be associated with power production? Is it inconceivable that there may yet be devised some chemical process of electricity production such as the direct transformation of coal gas into electricity, as referred to at the recent World Power Conference? And who would even dare to predict that, in the march of time through the ages to come, man shall never realize his dream of harnessing the stupendous radiant energy of the sun? The sceptic points out that although it requires only between 3 and 4 square miles of maximum solar radiation to be equivalent to the potential power of the Niagara Falls, yet the sum total of our endeavours to harness radiant energy has only given us so far the photo-electric cell. My reply is that electricity, as we know it to-day, sprang from the equally infinitesimal beginning of the voltaic cell.

EXPECTATIONS IN NORMAL DEVELOPMENT

But even disregarding altogether the effects of any possible new discoveries in the realms of production and application, what are the prospects of normal expansion over, say, the next 15 years? Rearmament is an incalculable factor in the present widespread economic recovery, but there is a growing opinion among economists that this recovery owes less to rearmament than was at first supposed, and that increasing production, falling unemployment, rising investments, increasing credit circulation, and some recovery in international trade, are simply characteristic signs that recovery is at last following the normal cyclical expansion after a period of intense depression. With this encouragement, therefore, and discounting any possibility of war, we can judge the trend of trade recovery sufficiently nearly to enable us to prepare our equipment to meet a reasonable expansion of consumption. Consequently, from a somewhat intensive investigation I have made, to the results of which I can only refer briefly in this Address, I have formed the definite opinion that it is reasonable to expect under present conditions a normal expansion in output during the next 15 years from 20 000 million units in 1936 to 55 000 million units in 1951, corresponding to an increase in maximum demand from 7 million kW at 33 per cent load factor to nearly 16 million kW at 40 per cent load factor, in coal consumed from 13 million tons to nearly 24 million tons, with an improvement from $1\frac{1}{2}$ lb. per unit average to 1 lb. per unit, and, if we assume a constant population, in units sold per head of population from 365 to 1 000. That these estimates are reasonable is borne out by the fact that they correspond to an average annual growth of 7 per cent compared with the present rate of nearly 13 per cent. Furthermore, I find that they support the convictions of our immediate Past-President, Mr. J. M. Kennedy, who, in his Address last year stated "I suggest, therefore, that we might well take Sir John Snell's estimate (made in 1926) of 47 000 million units as a goal to be aimed at in the next 10 to 15 years at the outside, in the confident anticipation that the potential domestic and industrial demand, as we shall then know it, will be far in excess of our present ideals." My own estimates indicate that we shall not be far short of attainment of this goal by the end of the next 10 years.

GENERATION AND DISTRIBUTION IN THE FUTURE

Anyhow, whatever may be our individual views upon the future, we are all agreed that we are at present only on the fringe of vast developments, and my one aim in these brief references to them is to stimulate and indicate a line of thought as a basis for future planning. That line of thought will naturally lead you to ponder the effects such developments as I have predicted are likely to have upon our generation and distribution facilities.

We have had 10 years of endeavour in the concentration of production, concentration in the sense of selection of the most efficient of the existing sources and of releasing their reserves of spare plant. Growth of load is already overtaking the released reserves in these sources, with the result that we are looking for new sites for our immediate needs. This search is bringing us into contact with certain social problems which are materially influencing our choice of site and causing us to ponder deeply as to whether we are taking a long enough view. The present tremendous concentration of general industry in certain districts, notably London, and the consequent movement of population, are creating difficulties in the electrical industry of which we are only now becoming aware. Fortunately, concentration of industry applies its own remedy. The choking effect of growth of population, load density, difficulties of coal transport, raw materials, and manufactures, will, in time, inevitably result in an increase in the now apparent movement of industry to the provinces and, therefore, also in the trend towards decentralization of control already manifesting itself in the examples of the G.P.O. and the railways in the establishment of more regional control. But it requires no stretch of imagination to foresee that in time to come provincial cities will also experience, although on a smaller scale, exactly those difficulties now being encountered in the capital, and in our own industry, therefore, it is imperative that we should anticipate that time now by such a programme in generation and distribution as will enable our resources to keep in step with any industrial or domestic movement and to meet any situation, even that of national emergency, with complete reliability and equanimity.

The changing conditions have already caused us to alter our conception of the relative importance of the three principal economic factors governing the choice of sites for steam stations, and are also introducing other factors. The ideal of a site near the centre of load, with consequent saving in cables, has been gradually controverted by such opposing factors as high cost of such a site, difficulties of coal delivery, of smoke abatement, of water pollution, and of exit of main feeders into streets already congested by electricity, gas, and water mains. In the early days of our history many of these factors did not have the preponderating influence they have now, and so to-day we find that stations which were erected on sites determined by the conditions then existing are now so completely surrounded by such a heterogeneous mixture of factories, business premises, and housing developments, and the many other modern requirements of ever-growing communities, that the majority of undertakings are rapidly finding that with these original sites it is economically impracticable to continue to cope with the accelerating demands of the communities they serve. Even the position of many stations built since the War is, generally speaking, such that with the efflux of time history will repeat itself, and they too may be absorbed or buried in the snowball effect of growth of communities. Admittedly the problem is difficult, but my own reflections thereon lead me to the conclusion that in the grid, or rather in the principle of interconnection embodied therein, we have a ready and flexible means of solving, to a great extent, the many difficulties involved in this problem in the future. In that respect, therefore, the originators of the scheme perhaps "builded better than they knew." That possibility was forecast by Sir Archibald Page in regard to one of the major difficulties, when in his presidential address in 1927 he stated: " It will be possible, with the grid, for generating stations to be correctly located away from centres of population, thus reducing the railway congestion caused by the carriage of coal to them and ensuring all the other advantages which accompany freedom in the choice of site."

Although originally intended, technically, purely as a system of interconnection of existing selected sources with the primary objective of eliminating other more wasteful sources, it is not a difficult matter to foresee that, within the second decade of the grid, this principle of interconnection will so influence the choice of sites that, when coupled with that greatest of all factors, security of supply, our conceptions of the relations between load centres and power sources may undergo an even more radical change than at first thought. Demand has nearly trebled in the past 10 years. Capacities of stations and sets have increased correspondingly. Security of supply, therefore, becomes more and more predominant, and interconnection is the means by which its dictates are carried out. Reliability is the factor which keeps a tight curb on any traditional tendency to concentrate the requirements of a whole community in one source. Money spent on straining after the last ounce of economy, on refinements which themselves may increase the risk of shut-down, on mitigating the more disastrous effects of fire and explosion hazards, on the more costly provision of adequate transport of coal without " bottle-necking," of storage facilities, of ash disposal and of smoke abatement, on controlling huge blocks of power in huge cables, will be diverted more and more in future towards increasing reliability of supply in the only way possible, and that is by decentralization, or rather limitation. Stations of the future, therefore, and their sites should have a definite ultimate capacity allocated to them which, even with plenty of space available for further extension, should not be exceeded, and additional requirements should be met by the provision of other and widely separated stations, each interconnected with the other.

Possible sites for such future stations should therefore be earmarked now. But where? So long as we have steam stations, adequate cooling-water supplies will always constitute the most influential of the technical factors effecting choice of site, and herein we begin to appreciate just how little actual freedom of choice we have. Taking a perspective of the country as a whole, we see that industry is spread throughout it in certain fairly well-defined areas concentrated around the estuaries of our largest rivers. It would be ideal if all future large base-load stations could be established in the open country between these centres of industry at points affording easy transport of coal, and easy interconnection between stations, and where land and rates would be comparatively cheap, but cooling water decrees that we have no option but to place new stations on the large traffic rivers feeding industrial centres, where sites are dearer and coal transport more difficult. The lava-like spread of industry down-river forces future stations, one after the other, farther and farther out on the estuaries, thus increasing difficulties of interconnection with other stations across the rivers, and in supplying existing main distributing stations at the load centres, nearer and nearer to the sea, increasing vulnerability in wartime.

The problem of the future, therefore, is whether we shall submit to this pressure in the hope that some day either concentration of industry will, as I said, apply its own remedy by removing to other centres, or new processes will transfer power production from rivers to pitheads, or whether we shall apply decentralization even more broadly and consider the practicability of sharing future base load with stations in the country on smaller rivers supported by cooling towers.

The technical aspects of this problem are intimately bound up with possible future developments in distribution, and here also is revealed the urgency for a far-sighted policy. Existing networks will, sooner or later, be unable to cope with the tremendous growth of load. Conservation of coal, conversion of slums, new housing schemes, new trading estates, huge blocks of all-electric flats, more costly mode of living, are all factors accelerating this growth in the domestic field alone. Consequently, it is only a question of time before we reach saturation of the streets with electric, water, gas, and telephone mains and sewer systems. Higher voltages of distribution appear to be inevitable, therefore, and it is not impracticable to envisage special street tunnels in the future carrying all power and telephone cables and all water and gas pipes, these tunnels feeding into substations built into the concrete basements, which will undoubtedly be a wartime precaution in all future large blocks of business premises, public buildings, and flats. It likewise appears reasonable to anticipate that all cities in future will be completely surrounded by a ring of high-pressure main feeders, laid in the arterial roads now being constructed and interconnecting a number of large transforming and distributing centres, from which lower-voltage feeders will radiate inwards to existing power stations and centres of distribution. These stations would then become the peak-load stations of the future, and all base load would be carried by new stations erected well outside city boundaries and connected to the high-pressure ring mains by single-circuit power lines to each of the main transforming centres, some from one station and some from another. Thus, generally speaking, every large town would have at least two base-load stations supplying it, from opposite sides, the equipment of which, and of the lines and transforming stations, would be operating at high load factor.

I can only refer very briefly to the future aspect of our generation and distribution facilities. Those who may contend that they are not problems for this generation should remember that this generation itself is paying the penalty now for just such an attitude of short-sighted policy on the part of the past generation regarding other problems. Engineers will never play their proper part in industrial reconstruction and in national welfare if they confine their attention to the requirements of this generation only and overlook their responsibilities to posterity. I stated that the policy of any industry is dictated by economics, and this is true even in problems where security takes precedence, providing a long enough view is taken, because it is almost axiomatic to say that any steps whatsoever taken to ensure continuity of supply under all conditions, including those of national emergency, must always be economical in the end.

SECURITY OF SUPPLY

This question of security of supply in national emergency has never loomed so large in the public eye as it does to-day, chiefly as the result of increasing governmental activity in the matter of air-raid precautions. The grid plan is now 10 years old, and these 10 years have kept the industry so busy converting that plan into reality that only now are engineers lifting their heads to look around and see what is going on in world affairs. And what do they find but the simple and illuminating fact, illustrative of the trend of thought and opinion to-day, that the man selected by the Government after the last war to plan the reorganization of their industry for peace-time has now been selected to plan another industry in preparation for the next war. One cannot be dubbed an alarmist to suggest that engineers themselves, therefore, can no longer evade issues already being faced by other industries.

I do not propose to discuss the immediate issues, of which we are all fully cognisant, beyond stating that there is a preponderance of factors supporting the view that in the instrument of post-War progress we have also a more reliable instrument of pre-War preparedness. To that extent, therefore, our industry is already playing a part in the endeavours of the nation to ensure peace for humanity in the only way possible, and that is by being prepared. It is all a question of degree, however, and consequently it is not inconsistent with my advocacy of a long-view policy in everything to suggest that it is not outside the bounds of possibility that some day sooner or later the national necessity of being prepared may override individual views and dictate that what has been done in the famous Maginot Line in France must be done with power stations of the future, and that extra expenditure thereon will rank in the national budget along with that for other defence services. As I have said, it is safer to predict what can be done than what cannot.

CONCLUSION

I have endeavoured in this Address to outline the potentialities of electricity, with the sole object of impressing upon our minds that, just as there is no limit to these potentialities, so likewise there should be no limit to our view of the future. I have endeavoured to infuse a spirit of meditation, to indicate a line of thought upon the future, to inculcate a flexibility of mentality such that we shall be instantly receptive to any changes in our industrial and social structure and shall, therefore, be ready to mould our policy and our plans accordingly. Above all, and finally, I have endeavoured to portray the destiny of the new engineer, whose more enlightened outlook born of a proper appreciation of his true worth to the community will find rich reward in administering the doctrine of electricity in the joys of peace and in the sorrows of war, in health and in sickness, in bringing comfort and happiness into countless poor homes by the relief of drudgery and the improvement in conditions of living and of working. " Electricity marches on," and in the vanguard must ever be the engineer preaching and spreading this new gospel for humanity.

SCOTTISH CENTRE: CHAIRMAN'S ADDRESS

By H. C. BABB, Member.

"RURAL ELECTRICITY SUPPLY"

(Address delivered at GLASGOW *27th October, and at* EDINBURGH *10th November,* 1936.)

In considering subjects upon which I might address you to-night, I have naturally gravitated towards one with which I am closely concerned, namely rural supply. Whatever may be the character of the distribution system with which he is concerned, it is now incumbent on the supply engineer to regard electricity as a necessity, and not merely as a luxury for which a luxury price must be paid. This is a growing feeling among consumers, and the supply engineer must adjust his outlook accordingly. Unfortunately this attitude toward electricity supply is naturally accompanied by a sense of grievance among members of the public residing in areas where a supply is not yet available, or where it is expensive compared with the price paid elsewhere, perhaps even close at hand. It follows, therefore, that if we are to regard electricity as a modern necessity, not only must our supply be plentiful and reliable but it must be made available everywhere within reason at a price within the range of all, and that without unnecessary delay.

The attainment of this ideal condition would appear, as things are at present, to be limited in varying degrees according to local conditions, rates of interest and redemption of capital, and so forth. As development proceeds (especially in rural areas) it usually becomes progressively more expensive to supply the remaining part of the community owing to the increasing paucity of load; it therefore follows that our constant aims must be to reduce the cost of leading a supply to the potential area or consumer, to bring down the cost per unit by every possible means, and to improve our load factor so that a larger turnover more than compensates for the small margin of profit per unit. In this way the electricity supply industry will not only tend to reach the ideal state already mentioned, but will attain to greater prosperity and will make an important contribution towards the welfare of the community. The last consideration applies with special force to rural areas, where anything that helps towards improvement of the amenities is of national importance in so far as it tends to stem the flow of people into the towns and cities and helps to keep the workers on the land, so maintaining the crops and food supplies of the nation. These benefits must in turn result in the increased use of electricity on the farm, and in the setting-up of industrial loads outwith the towns.

Whether we agree or not with their recommendations, it would appear that the McGowan Committee have appreciated the necessity for improving the present situation in regard to rural distribution, and have endeavoured to find some way of equalizing the conditions which exist in urban and rural areas.

With these considerations in mind it is proposed to review briefly the conditions governing rural supply in the past, to survey the present position, and to endeavour to offer some constructive proposals for the future. My remarks will be mainly applicable to conditions and supplies in Scotland and to the improvement of load factor in particular.

A REVIEW OF THE PAST

In the early days of electricity distribution the natural development took place in cities and towns, where a reasonably quick return on capital might be expected. Some rural areas were certainly served by the then existing power companies, but generally speaking such areas were left in the gloom, like Cinderella, to trim their oil lamps and perform other kinds of drudgery, while the towns increasingly camouflaged their ugly sister's drab appearance under the brightening influence and labour-saving utility of electricity. Industry, too, received a new fillip denied to the rural areas.

Technical difficulties also, such as the predominant use of direct current, which did not lend itself to long-distance transmission, tended to retard the spread of electricity beyond the town centres. With the development of alternating current and higher voltages, longer transmissions became possible, but still the cost factor stifled development, and town supply authorities were not prepared, or even permitted, to extend their networks to relatively unprofitable areas. Thus, in pre-War days, and in fact until the industry was put under the control of the Electricity Commissioners by the Electricity (Supply) Act, 1919, electrical distribution was more or less confined to the densely populated areas.

The Electricity Acts of 1926 were framed so that undertakers were given more security of tenure, and in 1928 the Electricity Commissioners revised the Overhead Line Regulations, making it possible to construct cheaper lines. In effect these changes gave a new lease of life to the companies, who were not slow to put up further rural lines and networks, and generally adopt some form of two-part tariff, which encouraged the consumer to use current for domestic purposes other than lighting. This led manufacturers to improve the design of electrical apparatus.

THE PRESENT POSITION IN SCOTLAND

Scotland consists of 29 800 square miles of territory, and the distribution of electricity over the portions for which Orders exist is entrusted to some 58 undertakings. Of these no less than 46 are concerned only in the supply to towns and compact areas, where the available load is concentrated and easily developed. In point of fact these authorities only cover approximately 357 square miles, or just over 1 per cent of the country, and the population concentrated therein averages 7 500 per square mile.

What, then, of the remaining 99 per cent of Scotland? A little over 10 per cent is covered by three counties who are developing within their own boundaries, either directly through the county councils or through a local electricity board. About 47 per cent is controlled by some nine companies, whose duty it is to develop the rural load over an area of 14 000 square miles, and in all these rural districts the average density of population is as low as 88 per square mile. The corporations, councils, and companies, therefore, are authorized to supply about 59 per cent of Scotland's area, leaving a relatively large rural portion distributed in the North and in the islands for which there is no provision whatever, or was not when these notes were prepared, and amounting to no less than 41 per cent of the total area of Scotland.

Approximately 66 per cent of Scotland's surface is composed of mountain, heathland, and deer forests, and even if we assume that the 41 per cent of highlands and islands which are uncatered for are entirely of this description, we are still left with the unhappy fact that of the 59 per cent authorized to the urban and rural undertakers, at least one-quarter of their territory is mountain and heathland so sparsely populated that possible further rural development seems negligible, while its character is such as to constitute a serious difficulty even for cheap transmission lines to link up the worth-while areas. Thus it will be seen that the authorities who supply towns have the majority of the industrial load, while those supplying rural areas have to incur large capital expenditure to supply comparatively meagre loads.

Figures, however, can be put in such a form as to appear to prove most things. It is evident that rural electrification *is* possible, but it is only made possible by the fact that most of the rural population is gathered together in small towns, villages and clachans, and in farms, and not distributed evenly at the rate of 88 per square mile. These small communities may be said to subsidize the extra-rural country surrounding them.

The Derating Act of 1929 was expressly designed to relieve agriculture and industry of the unfair incidence of rates for public services, of which they did not receive the full benefit, and thus put them in a better position to expand and develop. Whether due to this or other causes it is not within our province to say, but everything points to improving conditions, expanding trade, and greater prosperity, and it must be our aim and privilege to assist these tendencies.

If, therefore, the following remarks in any small degree stimulate thought towards ways and means of accelerating the increase in current consumption in sparsely populated areas, our ideal of a cheap and abundant supply will be brought appreciably nearer by the consequent increased turnover and decreased price per unit.

FUTURE DEVELOPMENT

(1) Legislation.

Having briefly stated our ideal and described the present position, let us now diffidently attempt to formulate some constructive and progressive programme for the future.

Broadly speaking, these suggestions can be classified under two heads: those over which we have direct control, i.e. construction and running costs together with exploitation of possible loads, and those we can only hope to make effective by building up a strong body of opinion within the industry.

Dealing first with what can only be made effective by pressure of opinion, I feel that I must specially refer to the extensive legislation now imposed upon us. This, while good in intention, is often so obscurely worded that those who have to translate it into everyday working language often find themselves in grave difficulties, in spite of every desire to comply with the intention and spirit of the law.

The present time, when new legislation is in contemplation, would seem opportune for members of this Institution individually to take stock of the position, and submit constructive criticism through the appropriate channels, with a view to action to ensure that new legislation will be as complete and clear as possible. I say this because it is my considered opinion that the influence of this Institution should play an important part in all electrical legislation.

As a first step towards future development, then, let us press for a consolidation of existing legislation, wiping out or amending obsolete and obscure clauses, and where desirable introducing new ones. Above all, let us call for principles to be enunciated in a clear and simple manner, so that all can understand and carry out the intention and spirit of the law without having to formulate individual interpretations after lengthy research through pages of legal phraseology.

The Overhead Line Regulations are, in my opinion, basically sound as regards factor of safety, but might, without danger, be relaxed in respect of the height of the lowest conductor. Even a small concession in height would appreciably cheapen construction. It is, of course, necessary to keep in each field one clearly-marked span high enough for the passage of rick lifters and the like, and road crossings should be of a similar height, but elsewhere across country it seems unnecessary for h.t. wires to be higher than is at present specified for l.t. wires.

The 1934 Regulations throw an unnecessary burden on the consumer by fixing the minimum multiphase load at 15 kW. The effect of this on small rural distribution is to force the undertaker to install an unnecessarily large 3-phase transformer to deal with relatively large single-phase loads, which could otherwise have been split over the phases of a 3-phase unit. The voltage-drop problem is also adversely affected thereby. In the end the consumer pays.

The McGowan Report should cause all the authorities to appreciate that electricity is a national necessity and no longer a luxury. It is, therefore, an opportune moment to press for legislation to prevent local assessors raising the rateable value of property when electric light is installed.

Derating might with advantage be extended to electricity undertakings, thus helping to penetrate more quickly into the domain of the already derated agricultural subjects.

The principle of amalgamation of rural and urban areas in some cases may prove to operate beneficially from a national viewpoint, but care must be taken to see that the Joint Board and Consultative Committee is adequately representative, in order to ensure equal treatment of rural and urban areas. As a basis of representation, some such figure as rateable value multiplied by area would seem to afford a reasonable solution. The longer security of tenure foreshadowed by the Report, coupled with an equitable basis of purchase, should do much to enable undertakers to amalgamate and to explore new outlets for the expansion of their rural networks. Most of the larger undertakers are already striving towards expansion through reasonable tariffs, cheaper construction, and assiduous salesmanship, and it appears probable that most of the smaller undertakers will profit willy-nilly in this respect through amalgamation.

(2) Exploitation of Possible Loads.

Scotland, although sparsely populated, has many natural advantages. In the North or Highlands there is considerable water power, and this is gradually being harnessed for the production of electricity, but, owing to its geographical position, long and expensive transmission lines are required to bring our commodity to the consumer. In spite of this, and in view of the rapid increase in electrical development, it is highly probable that these water-power schemes may prove a saving feature of the grid, especially for dealing with heavy peak loads. Mid and South Scotland provide a very excellent farming area side by side with large shale- and coal-fields and extensive industrial development. These, together with domestic users of current, can, if properly exploited, give an excellent diversity of load, resulting in a good load factor.

Generating costs are only a small percentage of the total supply cost, and therefore it behoves us to make a very careful study of transmission and distribution routes in order to ensure that lines or cables pass near the greatest possible number of potential consumers. The shortest line is not necessarily the most economical in the long run. If this thought is constantly before us there will be plenty of scope for load building without wasting time and money in chasing after original and unusual forms of load. Having placed our lines to the best advantage, let us concentrate rather on reduction of tariffs combined with sensible publicity, each of these helping the other.

Comparative costs of performing various services should be tabulated and published, and where for some processes electricity proves more expensive than other classes of power the comparative advantages of electricity should be clearly stated, and investigations should be made to see whether steps can be taken to reduce costs to a comparable level.

With the present tariff protection, dairy farming is coming more and more into its own. According to the index of British food imports, prepared by Oxford University, and taking the volume in 1927–29 as 100, the imports from foreign countries fell steadily from 116 in 1931 to 82 in 1935, and the Government policy of subsidizing small-holdings is having its effect on rural loads. For example, over an average number of farms the revenue from electricity supply per acre is 2s. 2d., while from small-holdings this is increased to 8s. 1d., with a corresponding increase from 9 units to 34 units per acre.

Against this, the capital expenditure per acre to give a supply will usually be larger for small holdings than for ordinary farms, the amounts in the cases quoted being 68s. per acre for small holdings, as against 6s. 9d. for farms.

The revenue, expressed as a percentage of capital expenditure, is, at present, only 13 per cent for small-holdings as against 33 per cent for farms, but with the development of domestic load to a relatively large number of small-holdings the revenue should steadily increase until the yield per £ of capital expended compares favourably. This steady increase is in fact evident from figures which show an increase of 125 per cent in revenue per acre in the fourth year.

The increasing public demand for pure and sterilized milk affords the supply authority an opportunity of pushing electricity for milking machines, sterilizers, etc., while the farmer himself is not slow to realize the advantage of electricity for motive power. As a diversion, it is interesting to note from the last census return that if every cow in Scotland were milked electrically the units consumed for this purpose alone would be in the neighbourhood of 11 millions per annum.

In the case of the small-holder, capital is not easily forthcoming for the installation of necessary apparatus, and unless the holding is farmed intensively it can hardly be expected to provide more than a bare living. It is in the national interest to make these small-holdings profitable and attractive, and it seems reasonable, therefore, to hope that the Board of Agriculture may do something toward the provision of capital for this purpose, and, if so, then the supply authorities must be alive to the possibilities of capturing this load, and not grudge the trouble entailed in nursing it during the embryo stages. We can even actively assist by means of hire, or hire-purchase, of installations and apparatus.

(3) Construction Costs.

I have already alluded to the necessity for careful choice of transmission routes, but coincident with this we must make a careful study of constructional methods, always striving to reduce our costs to the lowest level compatible with efficiency, and with one eye on future developments. The latter consideration is of paramount importance, bearing in mind that it is cheaper to make provision for heavy copper in the first instance than to increase later the size of a line and its equipment.

In the early days of electricity, cables were laid of a size which only provided for lighting loads. Subsequently these had all to be materially increased, and it is suggested that the same mistake should not be made in present-day distribution. While farms and rural places to-day use current for lighting and comparatively small power purposes, is there any reason to believe that developments will not take place in the same way as they have done in urban areas where consumers have become electrically minded ? Some undertakers run single-phase distribution over large tracts of territory, and it is suggested that considerable difficulties will be encountered as the load develops, and sooner or later 3-phase supplies will be demanded for motors and other apparatus. It appears that the best solution would be to erect lines capable of conversion, at a nominal cost, to the 3-phase system.

In considering this question of construction costs, a comparison between overhead and underground cables inevitably arises, and several papers given before this Institution within the last year or so have dealt with this subject.

Overhead lines erected under the present Electricity Commissioners' Regulations are constructed to withstand the usual conditions met with in this country, and these Regulations are wonderfully efficacious, but I wonder if we are proceeding along the correct lines? Efficiency must be the key-note of our endeavour if we are to make satisfactory progress in load-building, and reliability is an excellent measure of efficiency. The most soundly erected overhead line is subjected to all sorts of risks and dangers, and to climatic conditions which do not affect a cable buried underground. While the reason for the present popularity of the overhead line is primarily its cheapness, is it not possible to concentrate on bringing down the cost of underground construction to something approaching that of the overhead line, thus securing maximum reliability?

With an overhead line a number of maintenance charges are involved, which almost disappear when a cable is used, and, in addition, the life of a cable is probably five times that of an overhead line. While the present initial cost of the former is perhaps 2½ times that of the latter, not a little of the extra cost goes in excavating and laying charges. In rural districts it is often possible to run along hedges and in places where traffic is negligible, and there seems no reason why permission could not be obtained to lay cable at a depth of a few inches in such positions, providing suitable mechanical protection is afforded. Such mechanical protection has already been patented in the form of interlocking metal "tiles." These consist of channel-shaped sheet or cast metal covers having curved tongues. These tongues anchor the cover firmly over the cable when driven into the ground, each cover interlocking with the next one by means of a hook. The whole then forms a continuous metalclad covering for the cable. As the iron circuit is not complete around the cable, the regulation is not impaired, while the cover still retains a permanently earthed and continuous conducting medium.

A suitable track could easily be made by an ordinary plough, or better still with a weighted excavator such as is being used at Preston.

Manufacturers are now putting on the market a standard rural "H"-type lead-covered screened cable, which is unarmoured, and the costs in July, 1936, were approximately £234 per mile for 3-core 0·016 in. cable, and £340 per mile for 0·05 sq. in. I believe this cable has been approved in some cases by the Electricity Commissioners.

The abolition of armouring when under metal protection appears to be fully justified, and moreover has a beneficial effect in reducing voltage-drop.

Cable manufacturers have done much research work, but it will be incumbent on them to develop a series of reliable boxes suitable for sectionalizing and tapping this cable to give connection to apparatus *en route*. Such a system, it seems to me, would greatly reduce the present heavy overhead mains maintenance charges, and provide a supply which would be more immune from interruptions caused by lightning, birds, gales, vibration, and the like. If this suggestion is not at the moment acceptable for main lines, I feel that it could be applied with advantage to supplies to villages and mansion houses. A high-tension cable could be laid along the inside or outside of the hedges on the main road, and where passing through a village a low-tension main could be laid in the same trench (although through the village the depths would have to be increased). Owing to the rapid growth of housing schemes and buildings in general, the position of the load centre is somewhat unstable, but with such a system as I suggest it would be possible to tap off the high-tension cable at several points, as required, to meet the ever-changing conditions, and with suitable interconnection on the l.t. side duplicate supplies would be available and voltage regulation greatly improved.

(4) Reliability and Salesmanship.

The larger undertakings are already conscious of the necessity for an efficient sales organization, but the salesman must be backed by a reliable supply if we are to obtain the maximum results from his efforts. The satisfied consumer is probably our best advertisement, and this holds especially in rural work, for farmers meet regularly at the local weekly market and, human nature being what it is, they are apt, when satisfied with the working of their machinery, to proclaim its virtues to neighbours who have not been progressive enough to install electricity.

Reliability is not incompatible with cheap and simple construction—probably quite the contrary. Cheapness is a relative term, and if we can put down mains that do not involve high operating costs and that last longer, I suggest we are working on lines which, in the end, will prove the cheapest.

The problem of the rapid isolation of busbar zones in large oil-switch installations is one that is receiving much attention at present. The gases generated by the opening of a switch carrying a large current are a source of danger to busbar connections and may be the cause of a number of insulators breaking down to earth and the development of phase faults. The provision of protection gear on each section of the busbars in order to cut out a faulty section is an expensive and complicated matter. Some undertakers are at present trying out a system of earth-leakage protection for the busbars. The entire framework of the switchgear is insulated and connected to earth through current transformers, which are capable of opening the incoming switches on earth faults and rapidly isolating the busbar zones from the remainder of the system.

Lightning can play havoc with any overhead system, and the difficulties are increased by the inevitable fact that any conclusion drawn from observations on the effectiveness of protection are more negative than positive, for unless a breakdown actually occurs we are never quite sure whether our lines have been struck. Any type of lightning arrester should be capable of clearing a surge without becoming permanently earthed, and often I have known it to be otherwise.

The necessity for reliability applies equally to l.t. distribution, and here the most likely source of trouble is at the overhead lead-in to consumers' premises. When an overhead span is carried from the mains to the house wall or chimney, I have found that an excellent lead-in can be effected by plumbing a copper inverted " J " tube on to a sheet of lead, and inserting this in place of one of the slates, thus providing a watertight entry into the roof. The wires leading through this tube should be of a homogeneous type, possessing damp- and corrosion-resisting properties, ordinary vulcanized-rubber wires being likely to deteriorate more rapidly.

Having done our best in these and other ways to ensure a reliable service, we can send our canvassers out with the knowledge that their whole energy can be directed towards convincing the prospective consumer of the advantages of electricity for domestic and industrial purposes without their style being cramped by having to apologize for the deficiencies of the mains department.

The choice of a suitable man for canvassing work requires careful consideration. I am convinced that, generally speaking, a man trained as an engineer does not make such a good canvasser as one who has served his time as, say, an insurance agent, and who is willing to pick up just sufficient technical knowledge to enable him to talk intelligently of his wares. Rightly or wrongly, the canvassing of consumers is distasteful to the trained engineer and he will seldom make a success of it, except in the case of large industrial users where technical knowledge and experience are necessary and lend dignity to the business.

To be effective, a travelling showroom is in most cases too costly to justify itself in rural areas, owing to difficulties such as the obtaining of suitable positions, the problem of housing the attendants, and the weather. It is an advantage to follow up a canvasser's visits with a more moderate show of the apparatus he has been pushing, and this can be done with less expense on one of the construction or operation lorries during slack periods. In my opinion, cooking demonstrations are of real and constant interest to every housewife, and are the best means of inculcating domestic electric-mindedness. Although it is usually impossible to show a direct profit from showrooms, they tend to advance sales and provide personal contact between the consumer and the district staff.

It should be remembered that a strongly developed social side leads to harmonious working and tends to make those employed take a wholehearted interest in their work, and it has been repeatedly proved that it pays the management to foster such activities, even to the extent of a financial subsidy.

With such an incentive to enhance the goodwill and standing of the undertaking, the spirit of the staff is bound to permeate to consumers, both actual and prospective, with whom they come in contact, and the result is always increased proficiency.

IRISH CENTRE: CHAIRMAN'S ADDRESS

By WARREN STOREY, Member.

(ABSTRACT *of Address delivered at* DUBLIN, 29*th October*, 1936.)

At the opening meeting of last session I addressed you on the subject of electrical development on the Irish Railways during the past 25 years.* I do not propose to deal with a special technical subject this evening but intend to recall a few outstanding incidents and place on record a few observations concerning the history and value of the work of our Institution, with particular reference to the Irish Centre from its inception.

The outstanding event of last Session was the Faraday Lecture on "Television—An Outline," delivered by Dr. Mallett at the Gaiety Theatre, Dublin, on the 26th March. This proved most popular and attracted a large audience. Dr. Mallett treated his subject in a delightful and interesting way and his method of dealing with this new science was not only instructive but helped to remove many of the misconceptions which have arisen in the minds of the public as to what television really is.

The centenary of telegraphy will be celebrated in 1937, and in this connection it is worthy of note that The Institution was founded on the 17th May, 1871, as the Society of Telegraph Engineers, and its first Ordinary Meeting was held on the 28th February, 1872. Before proceeding to trace the history of The Institution further, it is opportune to state that the present year is also memorable as being the centenary of André Marie Ampère, the distinguished French scientist whose work in connection with electricity and magnetism is now so well known. Ampère is regarded on the Continent as the man who originated the idea of electric telegraphy and has been called the father of electromagnetics. The fundamental facts that he determined regarding what is known as the science of electricity in motion, inspired and made possible the great inventions in industrial machinery that have taken place.

I have not the time at my disposal to attempt to deal adequately with the work of this great man, but all electrical men will join with his own countrymen in doing him the honour that such achievement deserved.

HISTORY OF IRISH CENTRE

The history of The Institution has already been very clearly and concisely set out in a pamphlet entitled "History and Objects of The Institution" and I presume that all present are familiar with this interesting record. From about eight original founder members the membership has increased to over 16 000.

I should like to stress that one of the greatest advantages of membership was made possible by the establishment of Local Centres and Sub-Centres throughout England, Scotland, Ireland, and Overseas, the Irish Centre being one of the first of these. This arrangement has made it possible for our Irish members, while obtaining all the substantial facilities of membership of the parent body, to have the benefits of local control and influence. The chairman and immediate past-chairmen of each Local Centre are *ex officio* members of the Council of The Institution.

The electrical industry owes a deep debt of gratitude to the various members of the Council who have unselfishly and patiently given the benefits of their attainments, experience, knowledge, and discoveries, to the progress of electrical science and research, engineering practice, and kindred sciences. A great French writer makes one of his characters say "We truly give only when we give our work, our minds, our genius."

I have had an opportunity during the past few weeks of glancing through our history as recorded in our minutes, and have jotted down a few notes which I trust will be of interest.

The formation of a Local Section at Dublin was first approved by the Council on the 14th July, 1899.

A Committee consisting of Prof. W. F. Barrett (in the chair) and Messrs. Olsson, Porte, and Gill, is recorded as having met in Telephone Buildings, Dublin, in December, 1899, their duty being "to consider the terms of the Petition to the Council and order same to be duly forwarded."

On the 10th January, 1901, the Council agreed that the area of the Section should be that defined by a circle with a radius of 25 miles from Dublin. This area was increased on the 18th July, 1918, to embrace the whole of Ireland, and at the same time the name of the Section was altered to the "Irish Centre." As a result of the formation in January, 1936, of a Local Sub-Centre in Northern Ireland, operating directly under the Council, the membership of the Irish Centre was confined to those residing in the Irish Free State. The present total membership of Centre and Sub-Centre is 236.

The work of the electrical engineer has altered and increased tremendously within recent years, owing to scientific and industrial expansion, and we have now reached what is known as the "electric age." So far as our own particular country is concerned, the present policy of industrial development demands its contribution from our profession and industry to ensure and promote the successful development of such a policy. The members of our Centre have a competency in their profession that entitles them, either individually or collectively, to play an important part in this essential endeavour of the nation.

Our records reveal that most of the distinguished members of the electrical engineering profession in Ireland have been enrolled as members of our Centre and have contributed to its well-being and usefulness. Kindred bodies and the public have also recognized the value of the work of our colleagues to engineering achievements. As an instance may be cited the gift of the " Kettle " Premium which was placed at the disposal of the Institution of Civil Engineers in Ireland in 1931 as a permanent record of the public's appreciation of Lawrence J. Kettle's services to the community when city electrical engineer.

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* *Journal I.E.E.*, 1936, vol. 78, p. 62.

Our transactions show the wide scope of the Centre's contributions to the technical and industrial progress of the nation, and it is interesting to find that in 1907 the then Chairman (Mr. T. Tomlinson) dealt with the production of power and heat from peat in his opening Address. Also, at a meeting held on the 17th August, 1917, under the chairmanship of Capt. Webber, R.E., it was decided to request the Board of Trade Electrical Committee to take steps to ascertain the various places in Ireland where hydro-electric power was obtainable, and the amount of available power at each place, together with data giving the returns of water at different times of the year and available head. Also, on the 26th March, 1918, a special meeting was held in Leinster House to discuss the question of cheap electric power supply, with special application to sea-borne coal, home coal, peat, and water power. A further subject of discussion was the establishment of a high-pressure system throughout the country and the increased employment of machinery for:—

(1) Industrial purposes.
(2) Agricultural purposes.
(3) The establishment of electro-chemical works in Ireland.
(4) The application of electric power for traction:—
    (*a*) On railways
    (*b*) On canals.

On the occasion of the Ordinary General Meeting held at the Royal College of Science, 11th November, 1921, Sir John Griffith opened the discussion on the report of the Fuel Research Board on the Winning, Preparation, and Use of Peat in Ireland, and on the report of the Sub-Committee on the Water-Power resources of Ireland, with special reference to the Liffey Hydro-Electric Scheme. Perhaps what might be described as a sequel occurred in July last, when the Corporation of the City of Dublin, at a specially convened Meeting, conferred the Freedom of the City of Dublin on Sir John as a tribute to his great services to science and industry. Not the least of these great services will be realized within a short time when we inaugurate the great water and electricity scheme of Poulaphouca, when the dreams which he cherished will take tangible shape.

Dublin's Hydro-Electric Scheme.

The advantages of this scheme to our city and its ever-increasing suburbs, not only in assuring a reliable and essential additional supply of water to meet our insistent needs, but also in providing a source of power and light for domestic, industrial, and traction purposes, requires no emphasis from me. It is, however, only right to say that this development is in keeping with the policy of our Government and local authorities and is an indication of the progressive spirit that will restore our State to full economic freedom. The taxpayer and consumer might also be excused if they look forward optimistically to a reduction in rates and charges for current as a result of this reciprocal arrangement between the Dublin Corporation and the Electricity Supply Board.

Tracing our activities further I find that in March, 1924, Corporate Members of The Institution of Electrical Engineers were duly recognized under the standing orders of Dáil Eireann in connection with matters relating to electrical engineering, on the same basis as that of members of other similar professional bodies.

On the 2nd April, 1925, the great national electricity undertaking known familiarly as the " Shannon Scheme " was discussed at a special meeting of our Centre. Our first official visit to the Shannon works took place on the 5th and 6th October, 1927. In this connection I find in our records that the present Minister of Finance, Mr. Sean MacEntee, contributed an interesting and informative paper on overhead rural distribution in the Irish Free State during the latter part of our 1926–1927 Session.

In 1926 the members of the Centre paid an official visit to our broadcasting station, 2 RN. I am reminded of this visit by the very interesting Report that has just been issued by the Committee appointed by the Council of The Institution to report on Electrical Interference with Broadcasting. Some listeners in the Irish Free State suffer from this form of electrical disturbance, and its elimination is a matter of urgency. Suitable amendment of the Wireless Telegraph Act, 1926, would materially assist, and I am sure that the Department of Posts and Telegraphs will not delay investigation and action to ensure a speedy and effective cure. The causes of this disturbance are known to electrical engineers, and the devices for suppression which are available will, no doubt, be embodied in certain appliances. It is possible that all apparatus sold in future will have to be suitably equipped so that they will be interference-free. Regulations framed to ensure the incorporation of effective suppressors would, of necessity, have to include foreign as well as British products. The Committee's report is specially valuable, as it represents the considered opinion of the electrical profession on this important aspect of broadcasting.

With regard to our broadcasting service, we remember with pride and appreciation the way in which the engineering department of the Post Office had Athlone equipped in time for the great Eucharistic Congress in 1932.

In June, 1930, under the able chairmanship of Mr. T. J. Monaghan, Engineer-in-Chief, Post and Telegraphs, I.F.S., The Institution honoured us in Dublin and Belfast with a Summer Visit, the itinerary including most of the beauty-spots of Ireland. An interesting description of this visit will be found in the *Journal* (1931, vol. 69, p. 853). These Summer Meetings, which include a round of social functions, are perhaps the most enjoyable means of getting to know one another and of studying our various problems under the happiest conditions. I should like, on behalf of the Irish members, to extend a hearty invitation to our colleagues on the other side of the water to include Ireland again in their programme in the very near future.

Need for suitable Premises.

During the past years, through the courtesy of various bodies, meetings, lectures, and functions of the Irish

Centre have been held at various places in Dublin, including the Telephone Buildings, the former Royal College of Science, Royal Dublin Society, and latterly at the Physical Laboratory, Trinity College. Office accommodation at Foster Place for committee meetings and library purposes was also secured. It appears to me and, no doubt, to many of our members, that the time has arrived when the status, dignity, and activities, of our Centre call for suitable premises similar to those of sister institutions. I am aware that such a suggestion involves considerable initial cost and upkeep, but the achievement is worthy of a special effort by ourselves and sympathetic encouragement from our parent body. Big things courageously tackled are usually accomplished.

TRAINING OF ELECTRICAL ENGINEERS

Before concluding these recollections of our transactions it may encourage our younger electrical men to refer to an achievement which was recorded in the minutes of our General Meeting held in January, 1930, when Mr. Lorcan W. Kennan was presented with the Silver Medal awarded by the City and Guilds of London Institute for first place in the British Commonwealth in their examination, final grade, in electrical installation, and the Gold Medal awarded by the Electrical Contractors' Association to the apprentice indentured to any of its members who secured the highest place in this examination. This latter medal is accompanied by a cash prize, and the City of Dublin Corporation also awarded a scholarship to Mr. Kennan. I should like to stress that as the industrial side of our national life develops, we should aim at producing engineers and craftsmen with original minds and ideas, suitably trained to deal with the accompanying electrical development. The prestige and industrial efficiency and progress of our country demand that the future Irish electrical engineer must be trained scientifically as well as practically to hunt and harness the electron, and he should be provided with a course of works and laboratory research training, in addition to his university graduation. A university and technical institute training is insufficient for modern engineering, as the student must also be given practical experience in the use of tools and machinery, management and control of men, and up-to-date methods of costing.

These remarks must not be taken as a failure to recognize the great work of our universities in the education and training of the electrical engineer but as a plea for greater co-operation between the university and the industrial works for the benefit of prospective and selected students. Doctor Johnson's statement that "a university is a school where everything may be learned" requires qualification in the light of present-day needs.

Co-operative effort for the good of the profession and industry would also be assisted by exchange of visits between students of different countries, and we in Ireland would welcome visits from the London Students' Section.

ELECTRICAL DEVELOPMENT

It is now appreciated that electricity is a vital force in the world; it has facilitated research and developed technique in human affairs. It has made easy our business methods and our domestic problems in the home. It is now possible to obtain accurate time by dialling TIM on the automatic telephone. The development of electricity has encouraged our romantic dreamings by aid of the cinema, helped to reduce risk of accident, and overcome and alleviated suffering as far as is humanly possible. The wonderful curative agency known as electro-therapy is even yet not fully developed and its value to homœopathic research was demonstrated at the recent Homœopathic Congress in Glasgow. Electricity has also given us enjoyment in our leisure hours. Scientists and engineers may have, wittingly or unwittingly, injured the world by forging weapons of destruction, but they have also performed miracles in lessening and obviating risk to human life. A case in point comes to mind in what have been described as the successful wireless tests which have recently been carried out in a colliery in England, where experiments with short-wave transmission and reception appear to have established communication between the pithead and various points in the working. Any efforts which will reduce the ghastly toll of life in pit disasters should receive our support, encouragement, and unstinted help.

The steady growth in the use of electric current in this country during the past few years was recently shown in the Press. The growth in revenue since 1930 is given below.

	£
1930	478 006
1931	735 302
1932	938 933
1933	1 044 474
1934	1 149 684
1935	1 258 388

The report of the Electricity Supply Board for the year ended the 31st March, 1936, reveals a very promising state of affairs and shows a better return than any of the previous years. A profit of almost £1 000 per working day is shown on the year's working and it is apparent that the scheme is now developing a financial soundness.

As a railway engineer I feel that the future of our industry and commerce is vitally concerned with power and transport. Undoubtedly the time is fast approaching when substantial sections of our railway system will be operated electrically, resulting in increased speed, convenience, cleanliness, and lower costs, and the opening-up and extension of suburban districts. The first public electric railway to operate was the Portrush and Giant's Causeway Line, and the first private electric railway was the Bessboro' and Newry section.

With the development of our transport and our natural advantages, is it too much to prophesy that Ireland may become the centre of world and European Conventions? The introduction of the most modern methods of transportation on our railways and roads will ensure our industrial and commercial success. Undoubtedly, there will be expansion of aerial services for the transport of certain things and where exceptional speed is essential, also good roads will be found in the most remote parts of the country. I trust that the parking and garaging problem will by then have been satisfactorily solved, possibly by ramped storied garages on the " Hoenig " system. Action on the part of our civic authorities will inspire our architects and building engineers and ensure that our principal cities will be fairer and purer and unmarred by unsightly structures and degrading slums.

The adoption of electric traction will, as I have already hinted, have opened up and extended our suburbs in all directions, making it possible for our people to reside well outside the cities. Rail transport may also be assisted by underground sections which will relieve traffic congestion in our streets, and electrical development may possibly enable moving side-walks and escalators to operate. The great marine lake with all its amenities that has been dreamed of in Dublin will, no doubt, be an accomplished fact, and let us hope that our street name-plates will be illuminated. Maybe smoke abatement will be realized by centralized electric heating installed as part of the equipment of every house and establishment. Probably flat roofs on modern central railway stations will enable aeroplanes from all parts of the globe to alight and transfer passengers. Political and international conditions may have encouraged engineers to tackle successfully the much-debated Channel tunnels. Let us hope that our people will have developed the civic pride and appreciation of the fine arts that is so lacking to-day, that our educational methods will have progressed so that every child will have an opportunity of obtaining the highest standard as a matter of course and will be trained to be courageous, enterprising, resourceful, and responsible, and that political rancour and avarice in public and private life will have given place to good fellowship, common sense, and understanding. Working conditions are undoubtedly being tackled to meet the intensified industrial conditions, and we may look forward to a happier time for even the humblest member of the community.

CONCLUSION

In conclusion I wish to say that in my opinion the world's present ills are chiefly due to fear and unbridled ambitions, as well as economic reasons, and we, as individual engineers, and as an Institution dealing with a universal force, can continue to play a substantial part in the treatment and cure of these ills by using the international influence and means of communication that we possess. It is also our duty and privilege to endeavour to give ethics its rightful place in international affairs. To quote Wells: " Man is still only adolescent—his troubles are not the troubles of senility and exhaustion but of increasing and still undisciplined strength. As yet we are hardly in the earliest dawn of human greatness. Can we doubt that presently our race will more than realize our boldest imaginations, that it will achieve unity and peace, that it will live, the children of our blood and lives will live, in a world made more splendid and lovely than any palace or garden that we know, going on from strength to strength in an ever-widening circle of adventure and achievement ? "

I.E.E. BENEVOLENT FUND

In a special foreword to the 1935 list of subscribers and donors to the Benevolent Fund, the President stressed the need for supporting the Fund. I should like to appeal to our Irish members to help as generously as possible.

The Funds at the disposal of the Committee are quite inadequate to deal with the number of deserving cases that are occurring, and our own Centre has, I understand, very good reasons for giving substantial help to the Fund.

HAMPSHIRE SUB-CENTRE: CHAIRMAN'S ADDRESS

By R. E. G. HORLEY, Member.

"MODERN HIGH-VOLTAGE CABLES"

(*Address delivered at* SOUTHAMPTON, 14*th October*, 1936.)

Considerable progress has been made during the last few years in the construction of cables for 33, 66, and 132 kV. New types have been introduced and the transmission engineer must examine the elements of their design and the claims made for them before he can decide which cable system is most likely to meet his requirements.

It is interesting to compare the various types and to see whether their differences are those of constructional detail or of fundamental principle. But before considering new patterns we should not overlook the very considerable improvements in manufacture of the plain oil resin-compounded paper-insulated cables. These improvements are due mainly to the availability of materials of greatly improved quality. Cable-making machinery has also developed from the clumsy collection of parts of machinery into precision apparatus designed for the efficient performance of their special operations. Control of drying and impregnating processes has also been established on a more scientific basis, with considerable gain in the effectiveness and uniformity of these operations.

A great deal of study has been devoted to insulating paper, and collaboration between the cable maker and the paper maker has resulted in the production of paper of great uniformity and high quality. Modifications to the normal manufacturing process have been introduced, with the result that it has been possible to reduce the power factor of the paper.

The impregnation of the paper dielectric of high-tension solid-type cables with mineral-oil resin compositions containing 15 to 40 per cent of resin is now a well-established practice. It has always been a matter of difficulty, however, to maintain consistency in the electrical properties of such impregnating media, even when great care has been exercised in the selection of the ingredients.

The mineral oil constituent is subjected as a matter of course to a number of purifying and refining processes which yield a uniform product, chemically stable and capable of retaining its electrical properties over long periods of storage. On the other hand, the commercial gum resin with which it is usually incorporated is a material which, from its method of preparation and its chemical nature, is subject to considerable fluctuations in quality (even within a given commercial grade), leading to undesirable variations in the electrical characteristics of compounds prepared from it.

A moderately high standard can be maintained in such compounds only by using a high-grade gum resin having very good resistance to oxidation at the temperatures necessary to bring the resin into solution and to carry out the cable-impregnating operation.

Impregnating compounds having greatly improved characteristics are now obtainable by the use of resin from which impurities and undesirable components have been removed by a solvent process. In such a process a solvent is employed which dissolves the whole of the natural resin, allowing separation from extraneous matter, or alternatively a solvent is used which, in addition, brings about the separation of one or more of the normal components which have inferior electrical properties. An extension of this principle is the incorporation of the necessary quantity of mineral oil with the resin, while the latter is dissolved in the solvent used in the purifying process. The resultant combination of oil, resin, and solvent, can conveniently be put through a final purifying process consisting of simple filtration or an earth contact treatment before the ultimate removal of the solvent by vacuum distillation. .

These processes have made possible the production on an economic basis of highly viscous solutions of resin in mineral oil, having electrical properties not appreciably inferior to those obtainable in mineral oil alone. The use of these materials leads to greatly improved power factor in high-tension cables.

It should be emphasized that their adoption involves no fundamental departure from the practice which many years of experience have demonstrated to be sound. Life tests on cables, together with prolonged laboratory tests of the physical stability of compounds exposed to cable-operating conditions, have confirmed that the new materials are reliable in service. To give some idea of the magnitude of the improvements in electrical characteristics obtained, it should be remembered that, in 1927, Höchstädter and Bowden* suggested for specification purposes a maximum value for dielectric power factor of 0·015 with 25 per cent ionization between half and double working voltage, i.e. a power-factor change of 0·003 between these voltages.

Dunsheath† in 1933 showed results with a maximum power factor of 0·004 with ionization of 0·0005, and although he stated that these results were not the best they had obtained they still represent good average practice. As a matter of interest it should be noted that to-day it is possible to obtain specially prepared plain mineral insulating oil of suitable viscosity for use without addition of resin. This oil has a very low dielectric power loss, and if suitable precautions to prevent oxidation are taken, and low-loss paper is used, it should be possible to produce a cable having a power factor approaching 0·001. The advantage gained is, however, not very important, because at 0·003 power factor the dielectric watt loss is already very small and does not have much influence on the rating of the cables at the voltages for which this type has been used up to the present time. The ultra-low-loss cable will therefore be reserved, no doubt, for special purposes.

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* "33 000-Volt Cable Testing," *Electrical Review*, 1927, vol. 101, p. 894.

† "Ionization in Cable Dielectrics," *Journal I.E.E.*, 1933, vol. 73, p. 321.

It has been generally recognized for many years that if it is required to work a paper dielectric at high stress the impregnation must be complete, voids being eliminated. The thermal expansion of the impregnation medium and its effect on the lead sheath has also been well studied, and it is to overcome the difficulty that the more completely a cable is filled with compound, the greater is the possibility that it cannot expand without causing permanent stretching of the lead sheath and the formation of voids on the cooling part of the cycle, that engineers have been working for many years.

Hunter has made special claims for cables with oval conductors, that with rising pressure due to thermal expansion of the compound the conductor and insulation contracts along the major axis of the oval and expands along the minor axis. The approach to the round gives an increase in area, the difference between the area of an oval and circle of equal perimeter, and thus accommodation is provided for the thermal expansion of the oil.

It is well known that a circular cable of normal section will develop internal pressure of the order of 100 lb. per sq. in. if full load is switched on to it on a cold day, whilst it is claimed that in similar circumstances an oval cable will not develop more than 5 to 10 lb. internal pressure. It is curious that after oval cables have been in use more than 20 years these virtues have been discovered, and perhaps it is because it was not until the introduction of screening round the individual cores had eliminated other sources of weakness that the true merit was discovered. Many attempts have been made to overcome void-formation troubles due to the thermal expansion of the compound, and a number of them make use of gas as an elastic medium.

The first complete solution of the problem was discovered by Emanueli in the fluid-oil-duct cable now conveniently known as the oil-filled cable. In 1924, at Brugherio in Italy, a short cable line working at 132 kV was installed; this was the first cable to work successfully at this voltage. The impregnating oil was very fluid and with changing temperature could flow into and out of the cable through a duct provided in the conductor, which connected through the terminal ends with an oil-storage tank placed above. The successful trial of this line led to the installation in 1927, at New York and Chicago, of the first commercial 132-kV transmission lines. It was a bold step forward to double the cable voltage previously used, with a new impregnating medium and dielectric stresses considerably higher than had ever been employed in previous cables. The design of these cable lines from a hydraulic standpoint to suit the profile of the route along which they were installed was an innovation of first importance because it enabled the engineers to make sure that positive oil pressures would be maintained in every part of the cable, thus ensuring that no voids could be formed in the dielectric.

A careful study of the thermal constants of the materials used to build the cable was made, and calculations of the heat generated in the conductor and dielectric and dissipated from the lead sheath under different conditions of load and ambient temperatures formed a basis from which estimations were made of the oil movements for which accommodation had to be provided in the oil reservoirs connected to the cable. These 132-kV cable installations have been in successful operation now for 8 years and have been duplicated in New York. Similar lines have been installed in London, and a new milestone in cable progress has been passed with the putting into operation in April last of 220-kV lines around Paris.

For operation at 66 kV, oil-filled cables in single core were followed by 3-core cables, and in Newcastle a 66-kV 3-core installation has been working successfully since 1932, whilst in London the largest 3-core cable in the world was put into service last July.

At the present time over 800 miles of this type of cable are installed in Europe and America, of which about two-thirds is in Europe.

Operating troubles have been remarkably small. In America a number of lengths of cable had to be replaced owing to defects in the lead sheathing, and in the New York duplicate feeder some lengths were taken out because they were operating at an abnormally high temperature. This was found to be due to the use of defective oil caused by overheating when the joints were made; the replacement lengths, together with the rest of the installation, have worked without trouble.

In London some trouble has also been experienced with the 132-kV lines owing to defects in the lead sheathing causing leakage of oil. The lengths concerned have been located and dealt with at the most convenient times.

A new trouble also manifested itself in one of the London lines. Comparatively large volumes of hydrogen gas generated in the cable joints entered the oil ducts and interfered with the proper functioning of the cable. This was found to be due to the fact that in these cables a different grade of oil had been used. The oil was highly refined, with very good electrical properties, but it was subsequently discovered that in the presence of a small amount of air such as might accidentally be trapped in a joint, and under electric stress, this type of oil could be made to generate hydrogen gas. Emanueli discovered that this phenomenon was associated with the degree of unsaturation of the oil, and that oils with a certain proportion of unsaturated hydrocarbons were not only incapable of generating hydrogen but under the same conditions would absorb the gas as well as small amounts of air. This made it possible to effect a cure *in situ* of the cables impregnated with the fully saturated oil, and this was done by replacing the oil in the cable ducts with a special oil which blended with the remainder of the oil in the cable and produced a mixture with the correct degree of unsaturation.

Before considering other types of high-voltage cable it should be noted that in later installations the oil-storage tanks which are placed at a height above the cable, and for which suitable elevated situations cannot always be found, have given way to the gas-pressure-operated tank placed underground.

These pressure tanks are cylindrical steel tanks filled with a number of short cylindrical flexible-walled steel cells into each of which a certain quantity of air has been introduced, the cell then being sealed off.

The air in the tank surrounding the cells is removed by a vacuum pump and replaced with oil. A number of these tanks are connected at suitable points to an oil-filled cable line and then oil is pumped into the line to raise the pressure. This also raises the pressure in the oil tanks and partly compresses the air cells contained in them, so that by their elastic compression they are able to send oil into the cable if the pressure falls, or to receive oil from the cable as the pressure increases owing to the loading of the cable. It will therefore be realized that thermal expansion and contraction of the oil in the cable is taken care of in modern oil-filled cables by air or gas under pressure.

The possibility of controlling the movement of impregnating oil in the mass-impregnated cable has been considered for a great many years, and in 1927 a patent was granted in America to Fisher and Atkinson for a system in which gas at a pressure of not less than 100 lb. per sq. in. was to be applied to the central conductor duct of a compounded cable so as to prevent the formation of voids in the insulation. I am not aware that any installation working on this principle was ever installed in America, but the principles disclosed in the specification have since been proved to be theoretically sound.

In 1931, Höchstädter, Vogel, and Bowden, introduced the pressure cable to this country in a paper read before the Royal Society of Arts.* The broad principles of this system had, however, been published in the British patent specification of Höchstädter in 1927.

The pressure cable system is unique because the high-pressure gas is contained in a steel pipe line in which the cable lies and exerts its pressure to compress the cable as a whole. This method was adopted because it was found that it was much better to squeeze the insulation than to stretch it from the centre of the cable, on account of the inelasticity of the paper impregnated with viscous compound. It was also found that this squeezing process applied to a circular lead-covered cable resulted in the formation of creases in the lead sheath due to inequalities in the lead wall and to differences in the resistance to compression of different parts of the cable, especially in the case of 3-core cables, in which the packing in the interstices of the cores is somewhat softer than the core insulation. This difficulty was overcome by reducing the quantity of packing so that the cable became triangular in shape, thus providing three flat surfaces in the lead sheath which could act as diaphragms to transmit the gas pressure to the inside of the cable.

The idea of using the lead sheathing of the cable as a flexible membrane was rather surprising, as most engineers were under the impression that lead was essentially non-elastic, and previous attempts to find an elastic limit for lead ended in the conclusion that this was a material that would flow under any stress and had no restoring action.

Beaver had published† in 1929 an account of his investigation of this question and showed that lead behaved elastically at stresses below 250 lb. per sq. in. There still appears to be some doubt about this matter, however, as the results obtained by Waterhouse for the British Non-Ferrous Metals Research Association indicate that pure lead is not truly elastic at any stress, but that at stresses below 100 lb. per sq. in. the creepage is negligible, whilst a research report issued by the University of Illinois on the creep of lead stated that lead had no true elastic limit.

The principle of applying elastic pressure from the outside of the cable seems from results obtained to be sound, and a long series of loading tests or load stability tests made on this type of cable both in Germany and England, show that it is possible to work the cable at temperatures up to 80° C. without any adverse effects. The voltage/breakdown-strength of the dielectric has been shown to be very high and nearly equal to the maximum figure obtainable on specimen sheets of oil-impregnated paper prepared and tested under ideal conditions in the laboratory.

It has been found possible, therefore, to design the cable to work with dielectric stresses of about twice the value which would be possible if the pressure external to the cable were equal to that of the atmosphere. Insulation thickness of the same order as used in oil-filled cables can therefore be used, and important economies in the cost of the cable can be realized.

An interesting point in this connection is that since the cable depends on the external pressure for these improved results it is not possible during manufacture to make tests on the cable of the order normally prescribed as appropriate for the designed working voltage, and the cable would probably be tested with about half the usual routine test-voltage. Type tests, however, would no doubt be made on specimen lengths of cable installed in a pressure chamber where the "as installed" conditions would be provided.

It is very essential when the pressure cable is installed and working that the external gas pressure is maintained, and a system of gas cylinders with automatic pressure-equalizing valves is connected to the pipe line and arranged with warning devices to ensure that the voltage is cut off from the cable in the event of the gas pressure falling on account of leakage in the pipe line caused by accidental damage or other cause.

In order to limit the length of line affected by any leak in the line, the pipe is divided into sections by means of gas barriers, and an ingenious system has been devised for locating gas leaks in a section. This is done by sending measured volumes of different gases into the pipe and compressing them. After a certain period of time these are pumped out of the line and the volumes again measured. One of these pockets of gas is then found to have diminished in volume through feeding the leak and it is found possible to estimate the position it occupied in the line, thus giving an indication of the position of the leakage.

Höchstädter, in the development of his pressure cable, considered the alternative methods of applying gas pressure from a hollow duct in the centre of the cable or using a double lead-sheathed cable with a gas chamber between the two lead sheaths, or a single lead-sheathed cable in a steel pipe, and decided that the last method was the best.

Dunsheath chose a different method and decided to make use of a gas chamber inside the lead sheath, and

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* *Journal of the Royal Society of Arts*, 1931–32, vol. 80, p. 84.

† *Electrical Review*, 1929, vol. 104, pp. 96, 142, 187, and 734.

arranged it between the external surface of the insulation and the internal surface of the lead sheath. The conductor of the cable, instead of being formed of the usual stranded-wire construction, is made from segmental copper so as to form a smooth solid cylinder with no spaces for migration of compound or gas. The insulation is the usual mass-impregnated paper with an external screen of metallized paper. In the actual construction of the gas spaces considerable ingenuity has been shown, the space between the cable core and the lead sheath being divided up into a number of compartments to form gas cushions. First of all a spiral barrier is formed by lapping on a number of piled paper strips bound down on to the core by means of a final metal strip binder, specially coated with a low-melting-point alloy to enable it to solder itself to the lead sheath as it is applied in the lead press.

The cushions are formed by sealing-off a portion of each turn of the spiral chamber by means of a seal control which is made up of a wide strip of perforated paper, impregnated with a sealing compound, built half-way through the gas-cushion space. The object is to ensure that there is no longitudinal passage for the gas along the cable, either between the spiral barriers and the lead or around the spiral space.

After the lead-sheathed cable has been reinforced with non-magnetic tape, and the spiral space has been charged with gas at a pressure of about 12 atmospheres, the compound in the seal control tape gravitates to the bottom of the cable, sealing off each turn of the spiral gas space.

The seals are not capable of withstanding any considerable difference of gas pressure between cushions, and their function is rather to delay the loss of gas from a long length of cable in the event of puncture of the sheathing occurring at some point owing to accidental damage. Whether the elaboration is necessary and effective may be discovered when this type of cable is installed under working conditions.

Dunsheath has published results of long-time stability tests on cables for 33 kV and 66 kV working pressures, which show that this type of cable can be operated up to 80° C. at voltages corresponding to nearly 10 kV per mm with satisfactory results.

A variation of the internal gas-pressure cable developed by Beaver, which is called the "gas-filled" cable, has the merit of simplicity. Not only has no attempt been made to separate the gas and the insulation, but gas spaces of predetermined dimensions have been provided throughout the body of the insulation.

The gas-filled cable consists essentially of a screened stranded conductor, insulated with impregnated paper strips and then lead-sheathed and reinforced with metallic tapes and provided with a second lead sheath or with protective tape.

The conductor, after being stranded, is passed through a solid die in order to smooth out the surface corrugations and to provide a flat bed for the application of two or three thin metallized-paper screenings, which serve the purpose of screening the interstices between the wires in the outer layer of the strand, of presenting a smooth cylindrical surface to the dielectric, and of limiting the maximum radial dimension of any gas space within the dielectric to that of the thickness of the individual papers in the dielectric. The dielectric itself consists of pre-impregnated papers applied in air and varying in thickness from $1\frac{3}{4}$ mils at the conductor surface to $5\frac{1}{2}$ mils at the outer dielectric screening, and applied with normal manufacturing lays and with normal gaps between adjacent edges of paper laps. The outer boundary of the dielectric is screened with a 3-mil copper tape, applied with overlap, and the lead sheath is applied over this with a 20-mil diametral clearance. A copper-wire woven-fabric tape is applied over the lead sheath to provide a bedding for the application of two metallic reinforcing tapes, and then either a second lead sheath and the usual protective tapings, or alternatively a special non-fibrous tape and protective tapings can be applied.

The gas spaces are incorporated within the dielectric in the gaps between edges of adjacent convolutions of the spirally lapped pre-impregnated paper strips and also to a lesser extent (of the order of 0·1 mil radial thickness) between the faces of radially adjacent spiral strips.

After the cable has been laid and jointed, the whole interior of the first lead sheath is charged up with dry nitrogen to a pressure of 200 lb. per sq. in. (gauge), via special gas-feeding glands placed in close proximity to the sealing ends.

On the electrical side the design is such that no ionization can occur under any service temperature condition, up to 100° C. conductor temperature, at a voltage lower than at least twice the designed operating voltage. The maximum gas-pressure value used so far has been 200 lb. per sq. in. (gauge), and with this pressure it is permissible to work at a designed maximum electrical stress of 85 kV per cm.

The design on the physical side is such that sufficient gas space is provided within the sealed-off sheath to limit the pressure-rise created by the oil expansion, under increase of temperature, to a value which can be safely handled by the reinforced lead sheath. The soundness of the design has been demonstrated by running a length of cable with a gas pressure of 350 lb. per sq. in. for 9 months with daily temperature cycles in the conductor up to 70° C.

The cable can also be heated to 100° C. without fear of drainage of compound from the pre-impregnated paper dielectric.

Stability tests have been carried out on factory lengths of cable, laid and jointed under service conditions, and these have shown that the cable can be operated successfully with maximum stresses of 140 kV per cm and conductor temperatures of 70° C. without showing any signs of ionization. Power-factor/temperature curves up to 85° C. have been found to be practically flat with a value of 0·31 per cent at the latter temperature.

Hunter has pointed out that the logical development of these various types of cables using internal gas pressure is to use dry paper for the insulation and rely on keeping the dimensions of the gas spaces within the limits which will give freedom from ionization.

It is claimed that the dry-paper gas cable has the following advantages: (1) Low charging current; (2) a power factor as low as that found in well-impregnated cable, but with the added advantage that it does not change appreciably with voltage or temperature up to

80°–90° C.; (3) freedom from problems connected with expansion or migration of compound.

Disadvantages due to the use of dry paper are: (1) Higher thermal resistivity which, in unfavourable circumstances, reduces the current-carrying capacity of, say, a 132-kV cable by 10 per cent, assuming normal conditions of laying; (2) danger that in bending the cable the dry papers will not slide over one another freely, which may cause registration of paper tapes and leave gas spaces of larger dimensions than were originally intended.

A study of the various types of gas-pressure-operated cable makes it very evident that a perfectly sound lead cable-sheath is absolutely necessary. It was probably lead-sheathing troubles that led to the development of the " Oilostatic " cable in America. In this type 3 paper-insulated metal-screened conductors are drawn into a steel pipe-line which is afterwards filled with low-viscosity oil to a pressure of 200 lb. per sq. in. All these high-pressure systems require fairly complicated systems of pressure-maintaining and pressure-equalizing devices, usually coupled with some means of giving warning should the pressure fall below a certain predetermined value.

The oil-filled cable system has been very favourably received all over the world and has proved very successful, but it is recognized that increasing congestion in the streets of large towns makes it difficult to find accommodation for the rather large pressure tanks distributed along the cable route, and it is probable that new developments of this system will take account of this inconvenience.

The pressure-cable line installed between Hackney and Walthamstow has been operating satisfactorily for 4 years, and similar installations in Germany have been equally successful. So far no actual working installations of any of the internal gas-pressure-type cables have been reported, and there is no doubt that when all the types under consideration herein have been through the refining fire of practical operation the experience gained will enable a final design to be developed which will perhaps combine the maximums of simplicity and efficiency.

All the cable systems which have been considered, with the exception of the " Oilostatic," depend for their successful operation upon maintaining a positive pressure within the lead cable-sheath; the soundness of the lead sheathing is, therefore, a matter of first importance. It is very difficult, however, with intermittently operating lead presses as used in the cable industry to obtain a sheath which will stand the considerable pressures it is necessary to maintain within the cable. Even in the case of oil-filled cables, where the maximum pressure permitted is low in comparison with that of the gas-pressure type, trouble has, in a few cases, been experienced through splitting of the sheath. In every case of a cable sheath splitting under the action of internal pressure, or as a consequence of bending, it has been found that the lead splits along definite lines of weakness, and research has shown that this weakness is due to defective welds.

In the ordinary press it is necessary to divide the plastic lead stream in the die box in order to extrude it in tubular form around the cable, so that the two streams of lead have to amalgamate to form the piping. This results in a seam or weld extending through the sheath. This welding together of the streams of lead would not of itself constitute a weakness. Unfortunately, however, owing to the fact that the surface of molten lead in the container oxidizes through contact with the air, and to the necessity of frequently recharging the container, the charges of lead, instead of completely amalgamating with each other, are separated by an oxide film. As extrusion proceeds, the distribution of the oxide films is such that they are deposited along a considerable portion of the weld, thus making it a path of weakness.

The fact that progress in the design of high-voltage cables was limited by this weakness of the sheath increased the efforts being made to design a press capable of producing sheathing free from defective welds, and about 3 years ago a press working on a different principle was designed and has proved completely satisfactory.* In this type of press, molten lead from the lead-melting pot is led into the machine and is forced out in the form of a pipe without any contact with the air occurring, so that there is no formation of lead oxide, and weak seams, pin-holes, red-lead inclusions, and other known defects often found in lead-sheathing operations, are absent.

Cable manufacturers have quickly realized the advantages of this new machine and a number have already been installed and put into service, and there is no doubt that the hydraulic lead press, which has been used for the last 50 years, will be superseded.

The need of the electrical industry for greater reliability in underground cables, and for continually increasing transmission voltages, has been met by the cable maker with the use of improved materials, new designs of cables, and new machines to make the new designs effective.

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* *G.E.C. Journal*, 1936, vol. 7, p. 120.

TEES-SIDE SUB-CENTRE: CHAIRMAN'S ADDRESS

By W. S. RAMSDALE, Associate Member.

"TWO DISTRIBUTION PROBLEMS: LIGHTNING AND EARTHING."

(*Address delivered at* MIDDLESBROUGH, 20*th October*, 1936.)

So much has been written lately on electricity distribution that some apology is necessary for making it the subject of this Address, but the majority of the members of this Sub-Centre are engaged in other branches of the industry, and therefore, although I have nothing new to contribute to the subject, I trust that a short review of two distribution problems will be of interest.

PROTECTION FROM LIGHTNING

During the last 10 years, largely owing to the enterprise of the large power companies many hundreds of miles of 11 000-volt overhead lines have been erected in rural areas of this country, and this extension of supply into the country districts has brought with it a number of new and interesting problems. Perhaps the most serious is the question of protection from lightning, as it is an unfortunate fact that overhead lines designed for working at 11 kV, the voltage which has proved to be the most economical for rural distribution, are more susceptible to damage by lightning than either 66- and 132-kV lines or low-voltage lines. At the higher voltages the margin of insulation is such that the impulse breakdown voltage of the insulators is sufficiently high to withstand the surges induced by lightning, also such lines are usually provided with an earth wire placed at such a height above the conductors as to act as a screen. A continuous earth wire on rural lines cannot be provided for economic reasons, and its efficiency would be doubtful owing to the impossibility of supporting it at a sufficient height above the conductors. On the lower-voltage lines the design of the insulators is governed chiefly by mechanical considerations, and this leads to a higher factor of safety than is necessary from the electrical point of view. The result is that, while spark-over does undoubtedly occur on low-voltage lines, the power-frequency current rarely follows and the insulators are not damaged. An enormous amount of research work is in progress in connection with lightning phenomena, and the investigators now consider that the majority of flashovers are due to direct strikes. Practical experience in the field, as far as this country is concerned, does not appear to support this view, and the effects produced are easier to understand if we regard the disturbance as a wave of high potential induced in the line at the point in closest proximity to the flash. Experience shows that in practically every case where a tree situated within 100 yards of a line has been struck, a flashover occurs at the nearest pole. The wave travels in both directions from the point of origin, and if the amplitude exceeds the impulse breakdown voltage of the line insulators a spark-over will occur. If the spark occurs at an instant when the power-frequency voltage is at or near the zero it is probable that the insulator will be undamaged. If, however, the power current follows the ionized path of the spark the resultant arc will damage the insulator to an extent which is dependent upon the rapidity with which the fault can be cleared. As the main feeder switches must of necessity be provided with a small time delay in order to provide discrimination, main-line faults cannot be cleared instantaneously and the damage therefore varies between wide limits. It may only amount to a small discoloration of the glazing, or the insulator may be completely shattered by the arc. In a number of cases the original impulse spark punctures the insulator instead of discharging over the surface. Such a fault is extremely difficult to detect, and the line may be repeatedly made alive and trip again on each occasion before the insulator finally shatters. On the other hand it is probable that in many cases where insulators are found completely shattered the original cause was puncture by the impulse spark and not a discharge over the surface. Assuming that the amplitude of the wave is insufficient to cause a discharge on a line insulator, it will travel along the line and on meeting a point where there is a change in the surge impedance of the line, such as the junction of the overhead line and the windings of a transformer, there will be a piling-up of potential. Part of the wave travels on, and a part, the value of which depends on the value of the surge impedance, is reflected and this reflection may result in the amplitude of the wave being doubled at the transition point. This explains why the majority of the flashovers on pole-mounted transformer insulators occur on those transformers which are connected at the terminal poles of spur lines. Another factor to take into consideration is the steepness of the wave-front. The wave is promulgated along the line at the speed of light, and the time taken for the pressure to rise from zero to the maximum amplitude of the surge is equivalent to $\frac{1}{4}$ cycle of an alternating voltage of the same amplitude. With a steep-fronted wave this represents an extremely high frequency, and the impact of the equivalent of a very high-frequency e.m.f. on the windings of a transformer concentrates the surge voltage across the first end-turns of the winding for the short space of time during which the capacitance between turns is charged. It will be seen, therefore, that immunity from breakdown cannot be obtained by increasing the breakdown value of the transformer bushings, as this would merely increase the chances of breakdown of the windings, which is a much more serious matter.

A number of manufacturers are now prepared to offer what are termed "surge-proof" transformers, the windings of which are so designed both as regards the interturn insulation and capacitance as to enable the windings to withstand surges induced by lightning. Unfortunately such a design leads to a considerable increase in the cost.

The damage caused by lightning is usually confined to four or five spans of the line, and it would appear from this that the wave as it travels from its point of origin is rapidly attenuated and the amplitude brought down to a value which is harmless. Lightning arresters as a means of protection must therefore be ruled out, because the number required to give adequate protection would enormously increase the cost of the line. Even regarded as protection for individual transformers they cannot economically be justified on a rural distribution system. The interposition of a length of underground cable between the line and the substation as a means of protection for the transformer is also prohibited on account of the cost.

Before dealing with alternative methods of protection, let us consider the effect of a lightning storm on a typical rural distribution system. Such a system may supply a hundred or more villages and small towns, in each of which there will be small industrial power users such as joiners' shops, flour mills, garages, etc., and domestic consumers who rely entirely on electricity for cooking. An interruption of supply during the daylight hours is therefore a serious source of inconvenience and loss both to the undertaking and to consumers, and an interruption during lighting hours is equally serious. Within the next few years it is possible that, following the nationalization of the main roads, many miles of these roads will be lit by discharge lighting which will have to be supplied from substations connected to rural systems, and continuity of supply will become of extreme importance.

The 11-kV distribution system usually consists of either a number of radial feeders or a ring main radiating from a central substation. In either case there will be numerous single-phase spur lines connected to the main lines, and if the latter are in the form of a ring they will normally be kept open at one point and controlled at the main substation by two 11-kV circuit breakers fitted with overload and earth-leakage protection. The ring will be sectioned at intervals by means of pole-mounted air-break switches in order that sections may be made dead for maintenance purposes without interrupting supply to more than three or four villages at a time, and all spur lines will be protected by suitable high-voltage fuses.

The first intimation of trouble is given by one of the 11-kV feeder switches tripping out, and as attendance at the main substation is either continuous or is provided when thunderstorms are imminent the switch is immediately reclosed. This may occur several times within a few minutes. In approximately 90 per cent of such trip-outs it will remain closed, and as far as the bulk of the consumers are concerned there will only have been a momentary interruption of supply. The line has then to be patrolled and a visual inspection of each insulator made from ground-level until the damaged one is located and changed, as it constitutes an extremely weak point in the insulation of the line owing to its reduced breakdown value. This patrol on foot may extend over a distance of many miles and needs no little organization to ensure that it shall be completed and the patrolmen's reports received at a central point in as short a space of time as possible. In the remaining 10 per cent of the faults the switch trips out again immediately it is reclosed. This is usually due to an insulator being punctured or so badly shattered that the wet flashover voltage has been reduced to less than the working pressure. A punctured insulator may lead to lengthy interruptions, owing to the impossibility of detecting such a fault from the ground and the consequent necessity of climbing every pole after the fault has been located to a given section of the line by sectionalizing.

The means available for dealing with the lightning problem may be divided into two classes, firstly those which aim at the prevention of damage to the line and apparatus, and secondly those which make no attempt to minimize the damage but reduce the period of the consequent interruption of supply.

In the first class we have lightning arresters, but, as previously mentioned, these cannot be economically justified. Arresters may be found necessary for certain terminal points which experience has shown to be particularly susceptible to flashovers, but their cost is a serious item. Co-ordination of insulation may be classed as one of the methods of preventing damage. By this is meant that the design of the system as a whole shall be such that the impulse breakdown value of the various components shall decrease in the order of their cost and ease of replacement, i.e. a transformer bushing shall flash over before the windings fail, dividing-box insulators shall have higher breakdown values than line insulators, etc. There is no doubt that a system in which due thought has been given to these points will be more reliable than one in which components made by different makers are used without consideration having been given to their relative breakdown values.

A third method which is widely used on the Continent is the earthing of the high-voltage neutral point by means of a Petersen coil. This consists of a coil having an inductance of such a value that the current which passes when the star voltage of the system is applied across it is exactly equal to the capacitance current of the system when one phase is earthed.

If an earth fault occurs on a system protected by this method the capacitance current of the two sound lines tends to flow through the fault, but this leading current is neutralized by the equal lagging current taken by the inductance, which is now energized through the fault, and the resultant fault current is zero. It is possible, therefore, to run the system with a fault on one phase, and this is claimed to be one of the advantages of the Petersen coil. It is also claimed that it will render the system practically immune from lightning damage, as insulators will not be damaged owing to the inability of the power current to follow the spark over. The Petersen coil, therefore, appears at first sight to be very attractive, especially in view of the fact that the tuning is not critical, its operation not being greatly affected by moderate reductions or unbalancing of the line capacitance due to the switching-out of sections of the line. In practice, however, there are serious objections to its use on a rural system such as we are considering.

If an insulator should be punctured by lightning, although the system will continue to operate it is essential that the faulty unit shall be detected and changed at once as the next fault may be on one of the other phases and will immediately develop into a short-circuit and trip the line on overload protection. If this results in a reduction of the system capacitance current by 30–40 per cent, as it may well do in a rural system, the Petersen coil becomes inoperative just when it is most required, as several faults may occur in a few minutes during a thunderstorm. The detection of such a punctured insulator, however, would be difficult as the absence of earth fault current precludes the use of fault indicators to indicate on which section of the line a fault has occurred. Experience has shown that in many cases lightning faults are simultaneous flashovers of insulators on either two or three phases. In such cases the Petersen coil has no advantages as the fault is a short-circuit, and it is rendered inoperative immediately the faulty line trips. Summarized, the objection to its use are: (1) The system loses its flexibility, and discriminative earth leakage protection on individual feeders cannot be used; (2) long single-phase tees cannot be connected; and (3), whereas the number of interruptions of supply may be slightly reduced, those which do occur are likely to be prolonged, and the fact that the device is inoperative immediately following the tripping-out of any considerable section of the system may have serious consequences, owing to a second fault occurring before the coil can be adjusted.

Another device which may be included amongst those which are intended to prevent damage to the line is the expulsion tube. This has been developed in America, and an experimental installation is now being tried out in this country. In effect it consists of a tube of insulating material open at one end and containing an air-gap between two electrodes, one of which is earthed and the other connected to the line through a second (smaller) external gap. This device is connected at each insulator, and spark-over, following a lightning surge, takes place across the gaps instead of across the insulator. If the power-frequency current follows through it is said to be extinguished within $\frac{1}{2}$ cycle owing to de-ionization of the gap. This again appears an attractive form of protection, but its use entails a very considerable increase in the capital cost of the line, without any guarantee of complete immunity from future trouble. We are still faced with the problem of the simultaneous flashover of two insulators on different phases, and the action of the device under these circumstances is problematical. A further objection is the use of fibre or bakelized-paper tubes exposed to the elements. Experience with similar tubes used in conjunction with rural lines, although for a different purpose, has not been altogether happy.

From what has been said it would appear, therefore, that with the present state of knowledge there is no possible economic method of rendering an 11-kV rural system immune from interruptions of supply if it is situated in a lightning area, and all that can be done is to concentrate on limiting their extent and duration. This can be done by the installation of pole-mounted auto-reclosing switches fitted with instantaneous earth-leakage protection on important tee lines, and an easily renewable indicating type of high-voltage fuse on all other tees and transformers. These precautions will ensure that faults at individual substations or on tee lines are cleared without interrupting supply to the main line, and the majority of these flashovers will be cleared before the insulators are damaged.

The second essential is the provision of some means of locating a fault. Fortunately this is available at a reasonable cost and consists of two types of earth-leakage detector. The first consists of a current transformer of the core-balance type. A number of these are placed in series with the line at convenient distances apart, and each operates an indicator at the base of the pole. On the occurrence of an earth fault all the indicators between the main substation and the fault will operate, and the fault therefore lies in the section between the last indicator which has operated and the first which has not. The second type of detector is intended to be fitted on each pole and is connected in series with the ironwork on the pole head and the earth stake, thus enabling the pole where the fault has occurred to be quickly located. On a system equipped in this manner the duration of the interruptions can be very much reduced, provided that the patrol system is efficiently organized when a trip-out occurs. The duration of interruptions of supply is greatly affected by the weather; the difficulty of patrolling a line at night in blinding rain, changing insulators and possibly letting in a new span of conductor after manhandling the necessary gear over several ploughed fields, has to be experienced to be believed, and the fact that such work is carried out cheerfully and with every man doing his utmost without the incentive of any special reward is a fine illustration of the spirit of *esprit de corps* which exists amongst the workmen and staff of supply undertakings.

Protection against lightning remains a pressing problem which grows more serious with the growth of the rural systems. Until a solution is found it is apparent that we can only concentrate on measures (which I have indicated) to minimize the resulting interruptions of supply on the lines. Such measures inevitably add to the cost of distribution and because they are not spectacular they are entirely overlooked by the majority of consumers, who appear to consider that an overhead line consists merely of wires supported on poles, costing very little to erect and even less to maintain.

EARTHING

Now let us turn to the second problem which has been brought into prominence by the extension of supply into the rural areas. As long as distribution was confined to urban and suburban districts no difficulty existed in obtaining an efficient earth connection either at substations or on consumers' premises, and it was reasonably certain that in the event of an earth fault on a consumer's premises the total resistance in the path of the fault current would be sufficiently low to ensure the blowing of the fuses before the casing of the apparatus concerned could rise to a dangerous potential above earth. The resistance of the transformer neutral earth connection in a low-tension substation feeding an underground network may be almost negligible, but in the case of a pole-mounted substation having no lead-covered distributing cables and the neutral earthed to a plate or stake it is usually found impossible to reduce the resistance below 5 ohms. Figures as high as 100 ohms have been obtained, and the average is 10 ohms. On a 230-volt network having a neutral resistance of this value the maximum fault current is limited to 23 amperes, which is well below the rating of the main fuses of a consumer who utilizes the supply for cooking and heating. The same conditions which prevent the obtaining of a reasonably low earth connection at the substation, also obtain on the premises of each consumer, but the installation contractor, being for economic reasons unable to sink an earth plate, has to be content with driving a stake for the purpose of earthing the installation. The resistance of this may be anything between 10 and 300 ohms, depending on the type of stake and the nature of the ground. A fair average value is 20 ohms, and with an earth resistance of this value on the consumer's premises and 10 ohms at the substation the maximum current that can flow for an earth fault on any apparatus or wiring on the consumer's premises is 7·7 amperes, which is insufficient to blow any but the lightest of fuses. We are therefore faced with the fact that on such a network we cannot rely on fuses as a means of protection against consumers' apparatus becoming alive. The fault current will continue to flow and the casing of the faulty apparatus will be maintained at a potential equal to the product of the fault current and the earth-stake resistance, 154 volts in the example just mentioned.

There is also a second aspect of this question, i.e. the danger to both men and animals at the substation under such fault conditions. If the substation metal-work such as the switch cabinet, etc., is earthed to the same earth plate as the network neutral then it will reach a potential equal to the product of the neutral resistance and the fault current, 77 volts in the case we are considering. Pole-mounted substations have an irresistible attraction for cattle, and the ground in their vicinity is usually trampled and muddy, with the result that we have all the conditions necessary for the receipt of a severe shock by any unsuspecting member of the undertaking's staff who may attempt to unlock the cabinet. The danger of shock to cattle is equally serious and is aggravated by the fact that a shock at any pressure exceeding 10 volts may prove fatal. The average cow spans approximately 5 ft. when standing, and under fault conditions the potential gradient on the ground may well exceed 10 volts over this distance and thus make the ground surrounding the substation a death-trap for cattle until the fault is traced and removed. A solution of the earthing difficulty at the substation has now been evolved by connecting the transformer neutral to two deeply-buried earth stakes in bore-holes sunk by a well-sinking machine and connecting all the substation ironwork to a separate earth plate laid horizontally just below ground surface, at the position in which an operator would normally stand when carrying out switching or testing. This effectually removes dangerous potential gradients from the ground surface and prevents the ironwork attaining a dangerous potential, but we are still faced with the fact that it is in most cases impossible to attain a lower value than 5 ohms for the combined stake resistance. It will be agreed that from the technical point of view the conditions obtaining on consumers' premises where cookers, wash-boilers, small motors, etc., are in use are far from satisfactory, and I propose to review briefly the existing solutions to the earthing problem. The ideal is the provision of a continuous earth wire throughout the network, which would be connected at the substation end to the substation earth and to which the casings of all consumers' apparatus would be connected, thus ensuring a metallic return for all phase-to-earth faults. The cost of such a scheme is, however, too high and we are left with only two practical alternatives, the multiple-earthed neutral or the use of earth-leakage trip switches. Both systems are widely used on the Continent and in the Dominions, but in this country opinion is divided about their merits. It is certainly true that both systems have attendant disadvantages, both involve increased costs, and the adoption of either of them is not a matter to be undertaken without grave consideration. The multiple-earthed neutral system, as the name implies, involves earthing the neutral at more than one point, and to do this the consent of the Commissioners must be obtained. It appears to be a condition of such consents that the neutral conductors shall not be of a smaller section than the phase conductors, and this prohibits the application of the system to many networks. Theoretically the system is a complete solution to the earthing problem. The casing of all consumers' apparatus is connected to the neutral conductor, and the neutral is prevented from attaining an excessive potential by the multiple earth points on consumers' premises. On consideration, however, the system will be found to have many defects, only the most outstanding of which will be dealt with.

The chief of these is that its success depends on the multiple earths being of such a resistance that under no circumstances will the neutral conductors and appliance casings connected to it attain a potential exceeding 40 volts, 50 volts being by general agreement the pressure above which the danger of a fatal shock exists, and even this value of 40 volts is too high for farms, quarries, and similar premises. Admittedly consumers' earth faults will be cleared with the same certainty as short-circuits, but this does not apply to earth faults on the network and services, and, as long as there are trees in the vicinity of village networks, faults due to conductors being broken by tree branches during gales will continue to occur. The fault current in such a case and the resultant rise of potential of the neutral cannot be predicted, owing to the varying resistance of the earth itself affecting the distribution of the fault current. In other words the actual neutral resistance to fault current will always be higher than the calculated value of the multiple earths in parallel, with the result that potentials in excess of 40 volts may easily appear on consumers' appliances. There are certain other types of fault which may have dangerous consequences. The failure of a static balancer on a heavily loaded network will result in a rise of neutral potential. An open-circuit on a neutral conductor on a consumer's premises will result in the casing of his appliances becoming alive at full voltage immediately they are switched on. An open-circuit on the neutral conductor of a distributor will result in the appliances of all consumers beyond the break becoming alive at a pressure exceeding the limit of 40 volts immediately any one of them switches on an appliance, unless the earth connections on that section of neutral have an extremely low resistance. Nothing has been said regarding the alterations to consumers' wiring, and other complications which must follow on the adoption of this system, but the difficulty and expense which must be incurred in ensuring that the multiple earths shall have a sufficiently low value to ensure that the neutral potential shall never exceed 40 volts under any conditions, and the fact that under certain circumstances a danger is introduced which is as serious as the danger we are trying to obviate, is in itself sufficient to show that the multiple-earthed neutral is by no means a complete solution of the earthing problem as it affects the consumer. If this is conceded, only one remedy remains and that is the installation of earth-leakage trip switches. These devices were originally developed in Germany and consist of a small circuit-breaker, the trip coil of which is connected in series with an earth stake and the casing of the appliance to be protected. The trip coil, which has an operating current of approximately 25 milliamperes, will trip the breaker if the potential across it rises to 25 volts, and the impedance of such a coil is so high that the resistance of the earth stake may be as much as 300 ohms without increasing the pressure at which it operates by more than 3 or 4 volts. This device has only recently been manufactured in this country, and there is no doubt that it is the ideal method of protecting individual motors, cookers, washing machines, and similar appliances. In Germany it can be obtained in various sizes ranging from substation switches to domestic socket-outlets. The great advantage of this system is that it enables a cheap driven stake to be used for the consumer's installation. A stake which would be of no practical value if used for any other system of earthing gives complete protection when used in conjunction with this device. A test to ascertain whether it is in working order can be carried out periodically by the meter reader or by the consumer himself by simply pressing a button, and in the unlikely event of a defect developing in the device the consumer is in no worse position than if he were relying on plain earthing with a high-resistance stake. Time will not permit any reference to the practical application of the earth-leakage switch to the various types of installations, but those who are interested should read " Artificial Earthing " by T. C. Gilbert which fully covers the subject.

The adoption of this system or the multiple-earthed neutral will undoubtedly increase installation costs, and although plain earthing in rural districts is technically unsafe it is questionable whether expenditure on either of the two systems which have been described can be justified. When one considers the number of domestic appliances connected to a large system, the percentage which develop defects resulting in the casing becoming alive is extremely small, and will grow smaller as manufacturing methods and designs improve. The few fatalities one reads of on consumers' premises are practically all due to the disregard of elementary precautions, such as occurs in the use of portable apparatus in a bathroom or in additions made to an existing installation by an incompetent person.

With the gradual raising of the standard of installation work and the scrapping of the older types of apparatus the earthing problem will tend to decrease in importance, although there will always remain special cases where the installation of an earth-leakage trip switch will be desirable.

NORTHERN IRELAND SUB-CENTRE: CHAIRMAN'S ADDRESS

By T. T. PARTRIDGE, Member.

(ABSTRACT *of Address delivered at* BELFAST, 27*th October*, 1936.)

THE NEW SUB-CENTRE

This is the first meeting of the Northern Ireland Sub-Centre, and I feel that it is my duty to say a few words about the formation of this new Sub-Centre—a Sub-Centre which is to function directly under the Council of The Institution.

I have been a Member of The Institution for many years, but it was not until I came to Belfast some 4 years ago that I realized how serious a drawback it was to electrical engineers and wireless experts in Ulster that no opportunity existed here for the interchange of views and the spreading of expert knowledge on the latest phases of the work of the profession. The importance of Ulster, and of the Cities of Belfast and Londonderry in particular, obviously demanded a separate Centre of The Institution, quite apart from the fact that many of the members in Ulster had not the time for journeys to Dublin, and many of the younger members had not the money for such journeys. I found that a previous effort had been made to start a Northern Ireland Centre, and here I want to record the early work done by Mr. Whysall, the city electrical engineer for Belfast. It is not due to any special ability of my own that our efforts have now met with success; it is that the time is ripe for the change. Our efforts have been supported very loyally by our colleagues in Dublin, who placed no obstacle whatever in the way, and also by the Council of The Institution.

In concluding this brief introductory note I want to acknowledge here the work which has been done in the founding of this Centre by the Honorary Secretary, Mr. Girvan. He has been untiring in the work he has so loyally undertaken, and it is a great pleasure to be able here to acknowledge his assistance. I owe a deep debt of gratitude also to Mr. Whysall who has throughout been at my side with his advice and guidance—and with his long experience here in Belfast he has been a very great help to me and to your Committee.

I look forward with the greatest confidence to the future of this Sub-Centre and to the increasing usefulness of The Institution to the electrical profession in Ulster.

RECENT ADVANCES IN COMMUNICATION ENGINEERING

I propose to review in this Address the advances which have been made in certain branches of electrical science during recent years, and naturally I shall deal more closely with those branches with which I myself am more particularly concerned, namely telegraph and telephone transmission, and wireless.

It is interesting to note how the demands made by one branch, the improvements made to fulfil the requirements of a particular subject, bring about also vast improvements in other branches of the science. This is noticed particularly with regard to television transmission, and the transmission of speech by physical underground wires.

Co-Axial Cable

As you are well aware, much of the wireless broadcasting we hear is transmitted over telephone trunk circuits before the actual wireless broadcasting commences, and it was the demand for similar facilities in connection with television broadcasting that led to the development of the co-axial cable. Good-quality television demands frequency components from zero, or a very low frequency, to a million or more cycles per second, whereas the wireless transmission of good-quality speech or music needs only components from a low frequency up to several thousand cycles per second. The best telephone transmission lines of the ordinary underground loaded copper-wire construction can only be made to work with frequencies up to tens of thousands of cycles per second, as in the carrier systems to which I shall refer later, but this of course fell very far short of the millions required for television. The point is that, owing to loading, underground conductors only pass a narrow frequency band. Overhead unloaded conductors will, of course, pass up to a million or more cycles per second. The investigation and research necessary to solve this question of television transmission on a wide band of frequencies on a physical conductor was of course a most difficult and intriguing problem, but from these investigations has evolved the co-axial cable. One other remarkable result also came from these investigations, namely that the wide band referred to can be divided successfully into a number of separate channels to provide at the same time 200 or more carrier speech-channels over the same co-axial pair. The co-axial cable consists essentially of an outer copper tube $\frac{1}{2}$ in. or more in diameter, with a central solid copper wire about $\frac{1}{8}$ in. diameter running as exactly concentric or co-axial as it is possible to make it. In ordinary language this means one solid copper core inside, but insulated from, a cylindrical copper sheath.

Several methods are employed to keep the copper wire concentric, e.g. by means of insulating discs placed at intervals along the tube, or by means of an insulating spiral thread. Such a co-axial system will transmit the band of frequencies extending into that part of the frequency spectrum at present known as "radio" frequencies—but with the radical difference from a radio system of being confined to a small physical channel shielded from external disturbances so that the same frequency band can be used again and again in different systems without interference.

The Post Office Engineering Department is already busy with the provision of a cable of the "co-axial" type for television transmission between London and Birmingham, with a proposed extension to Manchester, Leeds, and Edinburgh. This cable contains four separate "co-axial" tubes, two of which may be used for television in either direction, and the remaining two utilized by means of band filters to provide 200 or more carrier telephone speech-channels between London and Birmingham. Repeaters are required at about every 7 miles, but as one repeater is sufficient to amplify the whole frequency band for one tube the total number required is not excessive, and complexity is only introduced at the terminal stations where the oscillators, modulators, demodulators, and selective band filters, are installed. Great advances have been made in television broadcasting during recent years, culminating in the regular television broadcasts now being transmitted from the Alexandra Palace, and the co-axial cable will prove a tremendous assistance in extending the transmission—while at the same time providing a large number of trunk telephone circuits for regular and daily use.

Ultra-Short-Wave Wireless Transmission

While speaking of television our thoughts naturally turn to wireless, and here in Northern Ireland particularly to the ultra-short-wave wireless transmission of telephone calls. I have already spoken in public of this service, but since it was introduced between Ballygomartin near Belfast and Portpatrick in Scotland on the 22nd December, 1934—not two years ago—the improvements which have been introduced are so great that I must refer again to the subject. As you know, the installation which has already proved such a success was more or less in the nature of an experiment. The 6 original circuits are still working and will continue to work, but 9 additional channels are being opened during the next few weeks with very definite improvements over the original 6, and now we are experimenting the transmission of carrier-wave telephone circuits over the ultra-short-wave system, and this I have no doubt will be followed by teleprinter telegraph transmission over the same system.

Now to come back to the subject of ultra-short-wave wireless transmission. I need not explain that the system works in with, or I might say is actually linked in with, the ordinary world-wide physical trunk telephone service. The speech is brought to Ballygomartin or Portpatrick by ordinary land lines, and the sea is bridged by a wireless link fulfilling all the demands which the land-line service can make upon it. I mentioned just now that the 6 original circuits opened in December, 1934, were more or less in the nature of an experiment, and the system followed upon experiments which for some time had been carried out by the Post Office Engineering Research Engineers at Dollis Hill, London, and in the Bristol Channel. At that time the requirements, so far as we knew them, were:—

(1) The two sites should be in optical range of each other since the ultra-short waves are likely to become somewhat erratic over non-optical distances.

(2) They should be at least $\frac{3}{4}$ mile from a main road to avoid interference from motor-car ignition systems.

(3) The economics as to electric power supply and the nearness to a main telephone physical-circuit route should also be met.

(4) The sites should preferably slope downwards in the direction of transmission.

The original circuits operated on wavelengths of about 5 metres. The aerials were designed to concentrate the transmitted and received energy in the desired directions and consist of a number of half-wave radiators, mostly of the horizontal type, fed in phase. All the transmitting arrays, 6 on each site and each tuned to a slightly different frequency, are grouped in close proximity to each other. The receiving aerials are also grouped together some 200 yards away in order to minimize "throw-in" between the go and return paths in each radio "4-wire" circuit. The radio-frequency energy is fed to or from the aerials by parallel open-wire transmission lines rigidly kept at constant spacing by pyrex tube separators, and special $\frac{1}{4}$-wave lines are used to match the impedance of the array systems to the surge impedance of the lines, thus obviating reflection losses. Twelve radio frequencies are used, 6 in each direction, the corresponding wavelengths all lying between 4 and 6 metres. The incoming speech on each channel is amplified and is then passed to a "Class B" modulator equipped with two 10-watt valves of special LS 5 X type, the output of which is arranged to modulate the voltage applied to the anodes of the high-frequency oscillator. The high-frequency power output from each transmitter is of the order of 5 watts, and the receivers used are of the super-regenerative pattern. Connection between the radio circuits and the land-line circuits is effected through suitable transformers at the radio sites, and hybrid coils are provided at the terminal exchanges, thus allowing the normal "4-wire" trunk telephone working to be adopted. Ringing is effected by 500-cycle tone generators, the frequency of which is interrupted 20 times per sec. The signalling equipment is adjusted to operate only when the ringing frequency is so modulated, in order to prevent false operation due to speech currents in the neighbourhood of the ringing frequency. The 6 circuits from Belfast terminate in London (3), in Liverpool (1), and in Glasgow (2).

I made it clear that this scheme was built up by the Post Office Research Engineers and that 9 additional circuits were now in course of construction. The equipment for these circuits, which is being supplied by Standard Telephones and Cables, Ltd., operates on a principle radically different from that already described. Instead of employing a separate transmitter and receiver for each channel the new system comprises two transmitters and receivers capable of carrying simultaneously the speech currents in both directions on all 9 circuits.

At the transmitter the speech currents from the 9 telephone lines pass separately through 9 speech amplifiers, modulators, and intermediate-frequency modulated amplifiers. Pentode valves are used in these stages, and high-stability auto-oscillators provide the intermediate-frequency carrier waves, ranging from 150 to 300 kc.

The 9 intermediate-frequency carrier waves, modulated by the various speech currents, are passed through filters and applied to the ultra-short-wave transmitter. The transmitter consists of a push-pull oscillator and a balanced push-pull modulated amplifier, and the output of the latter stage is directly coupled to the transmission lines leading to the aerial system. Radiation-cooled 3-electrode valves (50-watt) are used in the final stages.

The receiver may conveniently be divided into two parts. The first part is common to all 9 channels, while the second part deals with the individual channels and is therefore in the form of 9 similar circuits.

The first part of the receiver accepts the high-frequency carrier and amplifies it in a single-stage amplifier which operates on the carrier frequency and passes the band occupied by the modulation, i.e. ± 300 kc. The signals are then changed in frequency to 10 Mc after passing through the detector and beating oscillator circuits. The 10-Mc signals are then amplified by a 2-stage amplifier and fed to a double-diode-triode valve which performs the function of rectifier, automatic gain control, and monitor. The output from the diode occupies a frequency band from 150–300 kc and contains the 9 channel carriers and their modulation.

The diode valve feeds into a circuit which is coupled to the 9 channel selectors, each accepting the individual channel carriers and their modulation. They are all exactly alike except that each accepts a slightly different frequency. The filters are associated with the amplifying stage, which is connected to a double-diode-triode valve performing the functions of rectifier, automatic gain control, and audio-frequency amplifier. From the amplifiers the signals are taken direct to the line.

It is not possible at this stage in the development of ultra-short-wave radio links to say which of the two systems described above will ultimately be adopted for general use. It is interesting to us here in Northern Ireland that our station is in the forefront of this most important development, and we can, I think, make the claim that Northern Ireland is following worthily in the footsteps of that great forerunner in the world of electrical science—Sir William Thomson—who was born here in Belfast.

I ought to mention that five of the new ultra-short-wave circuits, in addition to the original six, have been in actual daily service for some weeks and the results are most satisfactory.

The Multi-channel Carrier Telephone System

When dealing with the co-axial cable I referred to the carrier telephone system and I will now go into the broad principles of carrier working, as this system, which has been introduced only during the past few years, brought in tremendous improvements over the old single-circuit physical-pair trunk working. The principle involves the relationship between a modulated wave and its component frequencies—carrier and side bands—and of course is made possible by the thermionic valve and the telephone repeater. The application of carrier-frequency systems to suitable physical lines, whether aerial wires or sea and land cable circuits, increases the number of trunk telephone channels available without the provision of additional wires. Between England and Holland 6 carrier telephone circuits have been provided on the two latest continuously-loaded paper-insulated submarine cables. On one of these 4 carrier circuits, 8 side circuits, 4 phantom circuits, and 4 super-phantom circuits, are actually in operation on only 4 quads, i.e. 16 wires. A submarine telephone and telegraph cable and associated carrier equipment between Australia and Tasmania is now completed. It introduces several new and interesting features, notably a co-axial type cable with paragutta insulation in two lengths, each of 81 nautical miles, to an intermediate island (King Island) which will be used as a repeater station. This system will provide initially 5 telephone circuits, 7 telegraph circuits, and a one-way reversible broadcast channel. The cable and equipment are being supplied by British manufacturers. Here in Northern Ireland we have a case of peculiar interest. The submarine cables between Ballyhornan and the Isle of Man are two in number and are both of the 4-core balata unloaded type without the usual anti-teredo brass tape. The carrier system which has been installed provides one single-channel system on one cable and a 2-channel carrier on the other, giving a total of 8 circuits on 4 pairs of physical wires. The installation is of special interest because it is housed in an unattended station at Ballyhornan, visited only once a week for battery-charging, etc. The electrical characteristics of these old-type submarine cables increase the technical difficulties of providing multi-channel carrier systems thereon. Recent research, however, has made it possible to install 3-channel equipment, and plans and specifications are at present being drawn up for the installation of such equipment at Ballyhornan. For land-line working here in Northern Ireland the 3-channel carrier is being rapidly introduced where underground cable cannot be justified immediately, and will shortly be in operation between most of the larger towns. It is already working between Belfast and Londonderry, Omagh, and Enniskillen.

Voice-frequency Carrier Telegraph System

I must now refer to the increasing importance of telegraph working. Here again the carrier system is introduced in the voice-frequency carrier telegraph system, which is becoming the general system in use throughout the world. The system is used for working between telegraph zones over 4-wire loaded and repeatered telephone circuits. The carrier frequencies are interrupted to form the signalling characters in a manner similar to that in which direct current is interrupted in a simple telegraph circuit. This may be considered as consisting of a steady carrier wave accompanied by side bands, the width of which depends on the signalling speed. Generally speaking, it may be said that the more rapid the signalling the wider the band of frequencies necessary to convey the signal. It is therefore necessary in carrier telegraphy to transmit a considerable frequency band in order to convey the signal, and the spacing of the various channels must be arranged accordingly.

Different carrier frequencies are used for each channel. The carrier currents are produced by a motor-generator set, and after modulation by the sending relays they pass through band-pass filters each adjusted to one of the frequencies. The outputs of these sending filters are connected in parallel, and all signals transmitted by a single system are mingled together on the line.

At the receiving end the various frequencies are separated by similar filters. The current received in each branch of the circuit is amplified and then rectified by means of a valve detector, and the rectified current is used to control the operation of a telegraph relay which in turn controls the operation of the telegraph receiver associated with that particular channel.

The transmission of the carrier current is controlled by means of telegraph relays connected in the associated local circuits, the windings of each relay being connected in series with the contacts of the associated telegraph transmitter, e.g. a teleprinter. The carrier current is generated and transmitted to line continuously, but during transmission the feed is short-circuited at intervals depending on the character being transmitted.

Range of System.

The number of telegraph channels of a given speed which can be obtained from a cable circuit depends principally upon the type of loading employed, and to a lesser degree upon the length and quality of the circuit. The maximum number of duplex circuits that can be obtained from one ordinary 4-wire telephone circuit with the system described is 18. In other words, 36 messages may be transmitted simultaneously over one 4-wire circuit.

Normally the systems are arranged for operation over 4-wire circuits; but should 2-wire working be required the maximum number of circuits obtainable is halved, i.e. 9.

The frequencies employed are odd multiples of 60 cycles per sec. occurring within the range of 400–2 500 cycles per sec. This arrangement, together with the fact that the frequency for each channel lies in the middle of the pass band, practically eliminates the inter-channel interference which is due to modulating effects occurring in loading coils and amplifying valves employed in the repeaters. The chief products of the modulation referred to are frequencies equal to double each of the carrier frequencies and to their sums and differences taken in pairs. They are even harmonics of the fundamental frequency and lie midway between the pass band of adjacent filters; consequently, they do not come within the pass range of the receiving filters.

The speed of working is 66 bauds, and this can be obtained on any channel without exceeding 25 per cent distortion of the signals. In practice 80 bauds can be obtained.

Variations of ± $7\frac{1}{2}$ db in transmission efficiency of the telephone circuit can be tolerated. This is accomplished by means of a special feature in the detector circuit which automatically corrects for such variations.

The system is normally operated on a 4-wire telephone trunk, the only modifications necessary being the removal of the terminal ringing equipment, and 4 wire-terminating sets and echo suppressors, also, where necessary, the inclusion of terminal repeaters.

Tariff "A" Teleprinter Circuits

Since 1927 the majority of cables have had their conductors arranged on the "star quad" principle, and on this type of cable the phantom circuits are generally unsuitable for telephone purposes. In consequence, therefore, of the large trunk development in this country a considerable number of telegraph pairs or circuits in excess of those required for public service have become available. This, together with the introduction of the page-printing teleprinter into commercial use, led to a decision by the Department to offer private-wire telegraph circuits to renters at reasonable tariffs.

There are eight such circuits in Belfast, terminating at London, Glasgow, and Sheffield. The circuits are connected via channels in the voice-frequency systems and work remarkably well.

Subscribers' Equipment.

This consists of a table suitably designed to carry teleprinter and associated apparatus. In the case of alternating current a rectifier is mounted underneath the table. No batteries are required at subscribers' premises.

Tariff "A" Equipment in Repeater Station.

The power supplies necessary are:—

(*a*) ± 80 volts, derived from existing ± 80-volt generator.

(*b*) ± 40 volts, derived from cells.

The panels and associated equipment are wired for $\frac{1}{2}$ duplex and two loop simplex working. One rack accommodates 6 such circuits. All panels are provided with dust covers.

The Teleprinter 7A.

The keyboard is arranged on the same lines as the ordinary commercial typewriter, with the exception of those characters peculiar to teleprinter working, such as "line feed," "carriage return," etc. The necessity for continuous attendance is eliminated by means of an automatic start-stop switch which is brought into action by the operation of the electromagnet armature upon receipt of the start signal. The machine stops if no signals have been received during approximately 100 seconds.

Answer-Back Unit.

This is operated by depressing "Fig. shift" and secondary characteristic of letter D. It provides confirmation that the machine at the distant end is ready for reception and, in the case of systems in which the teleprinter may be connected to any one of a number of machines, that the correct teleprinter is brought into action.

Testing Equipment.

Adequate testing equipment is provided in the repeater station to enable faults to be speedily located. Subscribers may have the choice of either tape- or page-printing attachment. It is interesting to note that when both subscribers have tape-printing attachments there is no need for visual indication when the end of a line is reached. When one subscriber has tape and the other has page, a visual alarm is fitted to that subscriber with tape attachment which operates when he approaches the end of a line, indicating that he will have to depress the line-feed and carriage-return keys to operate the printer at the far end.

All this may seem rather complicated, but in actual practice the system works admirably, the practical working by the operators being really a very simple process.

Automatic Traffic Recorder

An explanation of the arrangements which are in force for keeping under the most careful observation the service given by automatic exchange equipment, as regards both its adequacy and its functional reliability, will undoubtedly be of great interest to all present.

As regards adequacy of equipment, you are, of course, aware that the switching plant in an automatic exchange is not provided on the basis of one switch per subscriber's line. Even where the calling rate is the highest in the country, switch provision on such a basis is by no means justified. The switching plant is divided into groups, the groups being available to equal proportions of the subscribers' lines connected to the exchange. The switch quantities necessary for each group are determined by the number of subscribers' lines to which the group is available, the average number of calls made by each subscriber during the busiest hour of the day, and the average duration of a call. Even in a very busy exchange, the ratio of the switch quantities in a group to the number of subscribers' lines connected to the group is very small, for example, in Belfast Central Exchange the ratio is approximately 8 per cent. In determining the switch quantities necessary for a given group, the arrangement which is most economical, consistent with the provision of a satisfactory grade of service, is, of course, aimed at. It will be appreciated that if calls originated with a good degree of regularity, or, in other words, if the number of calls in progress simultaneously were constant for every instant of the busy hour, service conditions approaching the ideal could be given by simply providing this number of switches. Immediately a switch was released by the termination of a call it would be seized again by the origination of another call. The minimum of equipment would have been provided and no calls would be delayed owing to insufficiency of plant. In practice, however, there is not even a slight degree of regularity in the origination of calls and they may, with inappreciable error, be assumed to originate in a purely chance manner; consequently the computation of the switch quantities necessary is more involved than in the ideal case.

To assist in the computation of switch quantities a unit of telephone traffic has been adopted. This unit expresses the degree of occupancy of switches or circuits, during the busy hour, in call-hours; thus if in a group N switches are engaged for t minutes during the busy hour, the group is said to have carried $Nt/60$ traffic units. If the number of switches engaged in a group was observed at 1-minute intervals during the busy-hour period and found to be $N_1, N_2, N_3, \ldots N_{60}$ at the 1st, 2nd, 3rd, . . . 60th observation, respectively, the total traffic carried by the group during this period would obviously be given by the sum of the traffic carried during each minute of the hour, i.e. $(N_1 + N_2 + N_3 \ldots N_{60})/60$ traffic units. This, however, is also the expression which gives the average number of simultaneous calls during the busy hour. From this it will be seen that to determine the degree of occupancy of a group of switches in call-hours (traffic units) it is only necessary to average the results of observations on the number of switches engaged during equal intervals of the busy hour. Such observations (known as traffic records) are carried out periodically to ascertain whether, due to any increase which may occur in the average calling rate or average call-duration of the subscribers' lines, traffic congestion, and consequent deterioration in the grade of service, has taken place.

Up to the present these records have been taken manually and they have incurred considerable labour expenditure—in Belfast Central Exchange alone each record costs approximately 60 man-hours. Further, owing to staffing difficulties, it is not practicable to obtain a better average than that given by observations taken at 3-minute intervals. These disadvantages will, however, be overcome when the installation of automatic traffic recorders, at present progressing at all the exchanges in the Belfast area, is complete. With this equipment

(1) The labour expenditure incurred in taking a record will be reduced to that necessary for the reading of meters, on completion of the record, which indicate the number of busy switches or circuits in each group during the record.

(2) A greatly improved average is obtained since the "test cycles" are made by the recorder at 30-second intervals.

(3) The mistakes which are inevitable under manual recording conditions (e.g. the inadvertent omission, from the record, of an engaged switch which is very little removed from its normal position) do not occur.

The following is a very brief description of this equipment:—

The requisite quantity of 8-level, single-motion access switches, each level of which contains 50 contacts, is provided. The "privates" (i.e. the connections of switches or circuits which are electrically marked to indicate the engaged condition) of all the groups to be dealt with are connected, in group order, to these contacts. The "wipers" (rotating switch-arms, which are impulsed over the contacts) associated with the odd-numbered levels are fitted in the same plane, whilst those associated with the even-numbered levels are fitted to make an angle of 180° with the odd-numbered wipers in order that the latter will just complete testing all the contacts in their levels immediately before the even-numbered wipers commence testing the contacts in their levels. The first 6 of these wipers are connected in pairs severally to the wipers of a control switch. Each level of the latter contains 25 contacts, to which are connected the traffic meters. The impulsing of the access switch wipers is controlled by an impulsing circuit, which applies its cycle of impulses (of sufficient duration for one complete revolution of the wipers) at 30-second intervals. The impulsing of the control-switch wipers is controlled by the seventh and eighth wipers of the access switch. When the wipers of the access switch, during their operation, impulse to a contact associated with an engaged switch or circuit the earth connection on the latter actuates, via the wipers of both the access and control switches, the meter connected to the contact upon which the control-switch wiper is standing. When the access switch wipers have tested the contacts associated with the last switch or circuit in a group, an impulse is transmitted, via the seventh or eighth wiper of the access switch, to operate the control-switch wipers to the next contacts in readiness to record the succeeding group's traffic on a separate meter. An additional meter, known as a " test cycle " meter, is provided to indicate the number of complete cycles of test which have been completed by the access switches during the record. On dividing the readings of the traffic meters, referred to above, by the reading of the " test cycle " meter, the average number of simultaneously engaged switches or circuits in each group and, therefore, the traffic (in traffic units) carried is obtained.

Automatic Routiner

As regards the functional reliability of the equipment, a system of testing (known as " routining ") is carried out frequently in order that faults may be detected whilst in the incipient stage. It will be appreciated that, where such a large quantity of complex apparatus is concerned, the testing of every detail and facility by manual methods is very uneconomical. This disadvantage has, however, been overcome by the provision of the automatic routiner. This applies a cycle of tests in turn to all the switching apparatus to which it has been given access. It gives visual indication at every instant of the test cycle of the group and switch which it is testing and the nature of the test it is applying. When a fault is found the test cycle stops; an audible alarm and visual indications of the fault found, and the group and switch concerned, are given. When the routiner encounters an engaged switch, the test cycle automatically ceases and it recommences immediately the switch becomes idle. Whilst a switch is being " routined " it is guarded against seizure by a calling subscriber's line.

I have, of course, only briefly outlined the methods which are adopted to keep the grade of service given by the automatic exchange equipment under constant observation, but it will, I think, serve to convey some idea of the degree of importance which the administration places upon this responsibility.

You have read in the papers that the millionth subscriber's telephone station in London has been connected, proving how an up-to-date telephone system is appreciated by the public. During the next few years the whole of the telephone system in Northern Ireland will be automatic, following on the change-over to automatic working which was successfully effected here in Belfast on the 2nd November, 1935. Automatic plant is already being installed at Londonderry and Lisburn, and some 150 of the smaller towns will, it is hoped, be working on the automatic system within the next two years. It can be claimed, I think, that the electrical engineer, both in the field of research and the actual practice of the constantly increasing knowledge gained by scientific research, is meeting the demands made by the business man and the private citizen and is at the same time opening up new facilities to trade and national well-being.

ELECTRONIC OSCILLATIONS IN POSITIVE-GRID TRIODES, AND RESONANCE OSCILLATIONS IN MAGNETRON GENERATORS[*]

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[From the National Physical Laboratory.]

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SUMMARY

The paper describes the results of experiments made to determine the factors controlling the production and wavelength of those oscillations, usually termed electronic, which are produced in positive-grid triodes and the frequency of which depends primarily on the inter-electrode time of transit of the electrons. The frequency of the oscillations obtained in this way is so high (of the order of 10^9 cycles per sec.) that it is not possible at present to measure the dynamic characteristics of the valve used to produce them. It is shown in the paper that oscillations similar in character to the electronic oscillations obtained with positive-grid triodes can be obtained with the split-anode magnetron, at magnetic field intensities greater than the critical field at which the anode current decreases rapidly with increase in magnetic field. The frequency of these electronic oscillations is proportional approximately to the ratio of the anode potential and the magnetic field intensity applied to the magnetron, and by suitable choice of this ratio the frequency of the oscillations can be made low enough for ordinary radio-frequency measurements to be made on valve impedance in the neighbourhood of oscillation. This procedure was followed in the experiments described in the paper; and the results obtained at a series of frequencies between 6 and 15 megacycles per sec. indicate that, in the case of the magnetron, the valve reactance changes sign in the neighbourhood of these electronic oscillations. An analysis is given of the type of electrical circuit equivalent to the magnetron valve required to reproduce the type of reactance and resistance variation obtained experimentally. It is shown that this equivalent circuit is of the series form having negative inductance, negative capacitance, and negative resistance components, and that this type of equivalent circuit could be produced if the inter-electrode transit time of the electrons within the valve were comparable with the period of oscillations generated by the valve. Oscillations without any marked change in valve reactance were also obtained in the magnetron near the critical field condition.

(1) INTRODUCTION

The retroactive type of valve oscillator becomes increasingly difficult to operate at frequencies much higher than about 10^8 cycles per sec. It has been found, however, that a 3-electrode valve can be used to produce oscillations of considerably higher frequency by a method in which the grid of the valve is maintained at a high positive and the anode at a small positive or negative potential with respect to the filament. The chief characteristic of the oscillations obtained in this way is that the frequency appears to be dependent primarily on the inter-electrode transit time of the electrons within the valve. This empirical result led Barkhausen and Kurz[†] to suggest that the oscillations are due to a vibratory motion of the electrons between the filament and anode of the valve. Electronic oscillations can also be produced in a cylindrical-electrode diode,[‡] usually called a magnetron, when a magnetic field of suitable magnitude is applied in the direction of the electrode axis. The author has shown[§] that if the diode is constructed so that the cathode is external to the anode no external magnetic field is required for the production of the oscillations.

No satisfactory hypothesis has yet been put forward to account for the occurrence of electronic oscillations in thermionic valves. An experimental determination of the conditions required for such oscillations and also of the variation of valve impedance in the neighbourhood of oscillation might suggest a solution to this problem. The frequency of the oscillations obtained in positive-grid triodes, however, is so high that it is practically impossible to measure directly the constants of such valves. It is shown in this paper that electronic oscillations of relatively low frequencies are obtainable from magnetrons, and a standard method of measuring reactance and resistance at radio frequencies has been adapted to determining the equivalent circuit of such valves in the neighbourhood of oscillation.

(2) ELECTRONIC OSCILLATIONS IN TRIODES

According to Barkhausen and Kurz, the periodic time of the electronic oscillations produced in a positive-grid triode is equal to the time of transit of electrons from the filament through the grid mesh to the neighbourhood of the anode and back again to the filament. This relation between the wavelength of the oscillations and the inter-electrode transit time of electrons is found in general to be approximately correct. Gill and Morell[||] showed, however, that under certain conditions the frequency of the oscillations is dependent to a large extent on the dimensions of the external circuit. These two apparently contradictory results led to the belief that there are two types of electronic oscillations[¶] the frequencies of which are determined in one case by the velocity of the electrons and in the other by the impedance of the external circuit. The two types of oscillations are not distinct and really represent slightly different operating conditions of the valve.

The interpretation of the results obtained with the

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[*] The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

[†] *Physikalische Zeitschrift*, 1920, vol. 21, p. 1.

[‡] H. YAGI: *Proceedings of the Institute of Radio Engineers*, 1928, vol. 16, p. 715.

[§] *Wireless Engineer*, 1934, vol. 11, p. 118.

[||] *Philosophical Magazine*, 1922, vol. 44, p. 161.

[¶] H. E. HOLLMANN: *Proceedings of the Institute of Radio Engineers*, 1929, vol. 17, p. 229.

conventional type of triode is complicated by the fact that the leads to the electrodes form an appreciable part of the external circuit and, consequently, it is difficult to estimate the true impedance of the circuit at the frequency of the oscillations. In order to reduce the effect of the leads, a special design of valve was used in the following experiments. In this valve the anode was divided longitudinally into two segments, and short leads were brought from them to two terminals on the top of the glass envelope. By connecting the external circuit between the two anode segments the total length, and therefore, the impedance of the circuit at the oscillation frequency, could be determined within narrow limits.

(a) Dependence of Oscillation Wavelength on Length of Circuit

In the first experiment a transmission line about 700 cm in length was connected between the anode segments and terminated in a resistance having a value equal to the surge impedance of the line. The external circuit was formed by that part of the line between the valve and a movable short-circuiting bridge placed across the line. For a given position of the bridge which remained connected electrically to the negative end of the filament, the filament current was adjusted for maximum anode current for grid voltages of 60 and 120 volts. In the absence of oscillations there was no anode current, so that the condition for maximum current may be assumed to be approximately that for maximum oscillation intensity. The wavelength of the oscillations was measured under this condition for the two grid voltages and also for different positions of the bridge on the wires. The results are shown in Fig. 1, in which the wavelength of the oscillations is plotted as ordinate against the corresponding length of the circuit as abscissa. It will be seen that for each grid potential a certain range of wavelengths is obtained and that in some cases a series of discrete wavelengths is possible for one circuit length. In order to obtain this variation in wavelength with or without change in circuit length the filament current (and therefore the grid current), had to be increased as the wavelength of the oscillations decreased. This characteristic is shown in Fig. 2, in which the wavelength of the oscillations for a grid voltage of 120 volts is plotted against the required value of grid current. It will also be noted from Fig. 1 that the mean wavelength decreases with increase in grid voltage. If, as the Barkhausen–Kurz hypothesis requires, the wavelength λ of the oscillations is proportional to the inter-electrode time of transit of the electrons, the wavelength should be inversely proportional to the average electron velocity. This, in turn, is proportional to the square root of the grid voltage (V_g), so that

$$\lambda^2 V_g = \text{constant} \quad . \quad . \quad . \quad . \quad (1)$$

The change in mean wavelength for the given change in grid voltage shown in Fig. 1 is approximately that required to satisfy relation (1). This result indicates that the oscillations are in some way related to the inter-electrode transit time but that for a given transit time a certain range of wavelengths is possible. This point is brought out more clearly in the experiment described below.

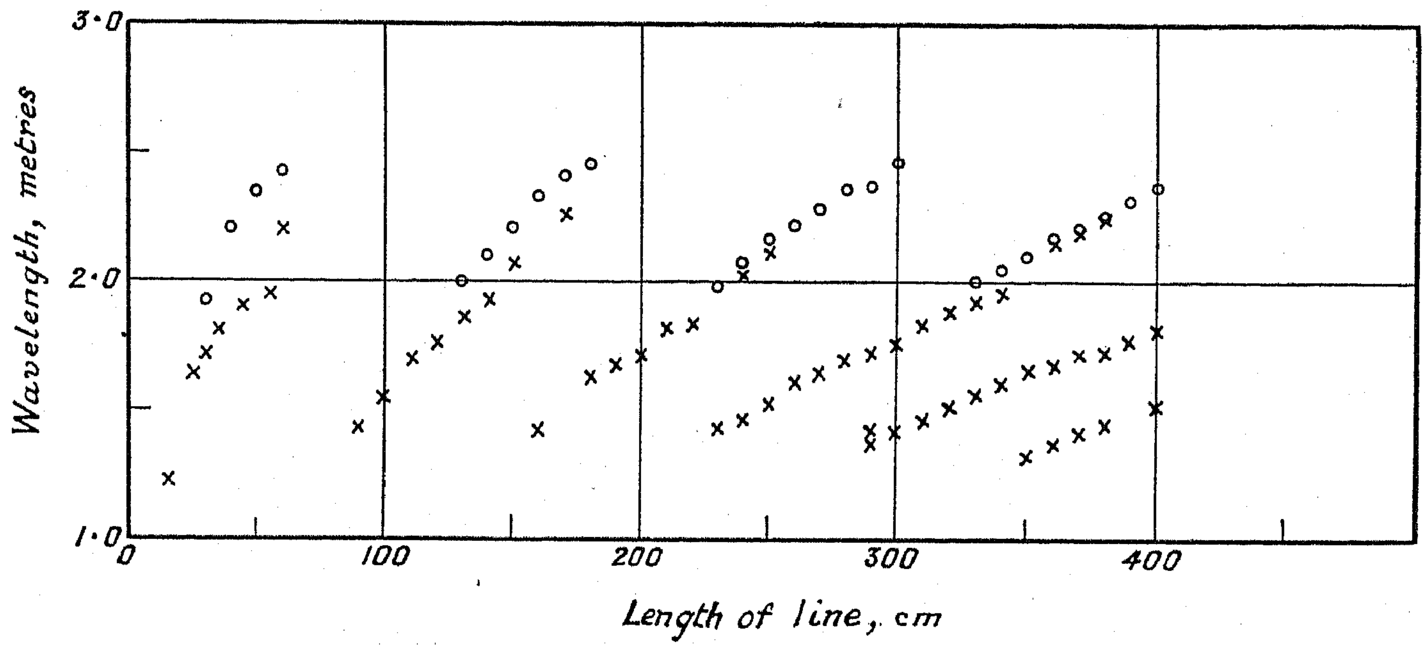

Fig. 1.—Dependence of wavelength of oscillations on circuit length, for split-anode triode.
○ ○ ○ ○ $V_g = 60$ volts.
× × × × $V_g = 120$ volts.

(b) Dependence of Oscillations on Reactance of Circuit

The experimental points in Fig. 1 lie closely to a series of lines radiating from the origin and given by

$$\frac{l}{\lambda} = \frac{2n+1}{4} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

in which l is the length of the external circuit, λ is the wavelength of the oscillations, and n has the values 0, 1, 2, etc. The reactance of a closed parallel-wire system for different values of the ratio of length of line to the wavelength at which the reactance is measured, is shown in Fig. 3. In the neighbourhood of values of l/λ given by

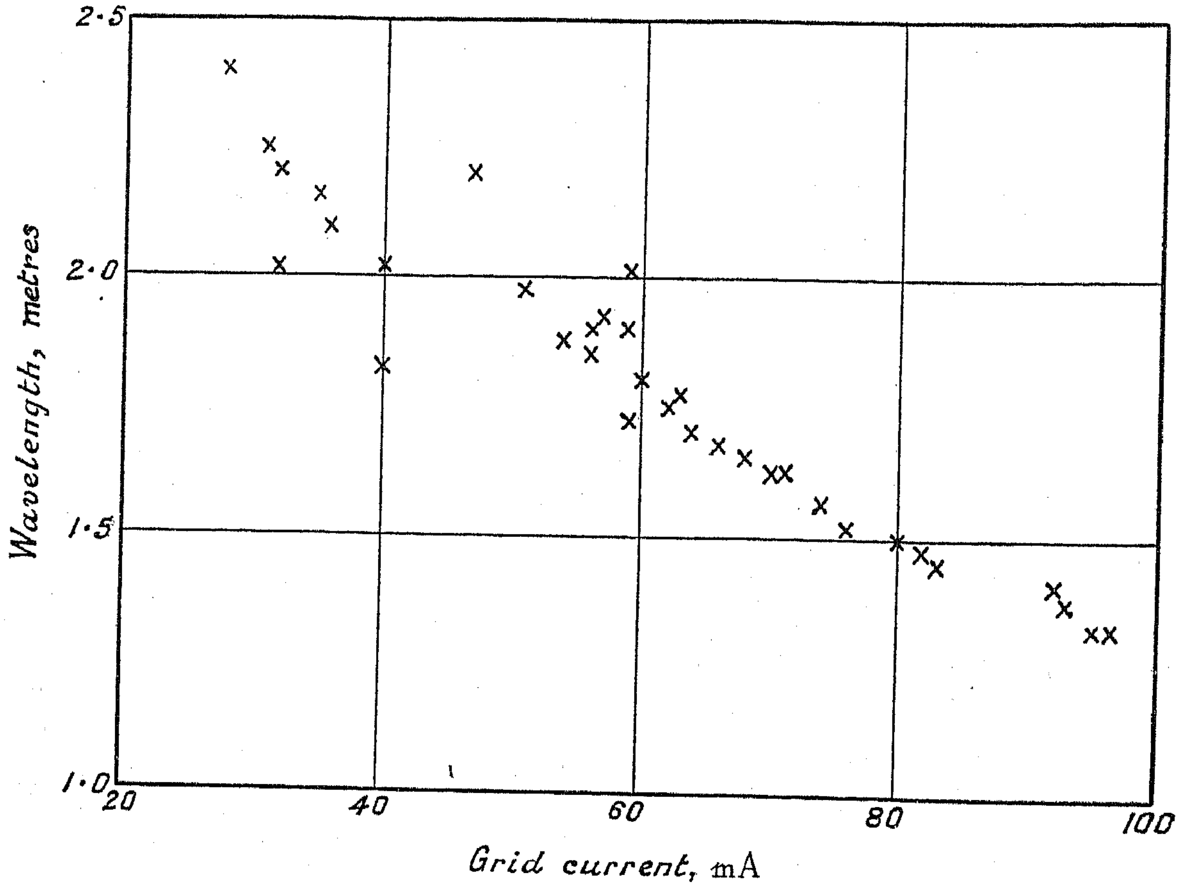

Fig. 2.—Relation between wavelength of oscillations and grid current ($V_g = 120$ volts).

relation (2) the reactance changes sign, and thus a very small change in the magnitude of l/λ in these regions is sufficient to change the sign of the reactance of the external circuit. The results given in Fig. 1 are not sufficiently accurate to determine whether such a change took place over the range for which oscillations were obtained. The experiment was repeated, therefore, for short lengths of external circuit, and in this case for each length of circuit the wavelength of the oscillations was determined for a series of values of filament current, the grid current being observed as a convenient method of measuring the change in space-charge conditions produced in this way. The results are shown in Fig. 4, in which the dotted line is given by $l/\lambda = \frac{1}{4}$. Reference to Fig. 3 shows that the reactance of the external circuit is positive or negative according as $l/\lambda <$ or $> \frac{1}{4}$; that is, as the point considered in Fig. 4 lies to the left or right of the dotted line. Since the valve reactance measured between the anode segments at the frequency of the oscillations must be equal and opposite to that of the external circuit, the valve reactance is negative for points above the dotted line and positive for the remainder. This result suggests some sort of resonance within the valve, the resonant wavelength for a particular space-charge condition being given approximately by the point of intersection of the dotted line with the experimental curve. It will be noted that for a given grid-potential (60 volts in the present case) the resonant wavelength increases with decrease in space-charge density within the valve. As the wavelength appears to be dependent to a large extent on inter-electrode transit time, this means that increase in space-charge density must decrease this time. A simple hypothesis for this result, first given by Gill,* is that for the production of electronic oscillations of appreciable

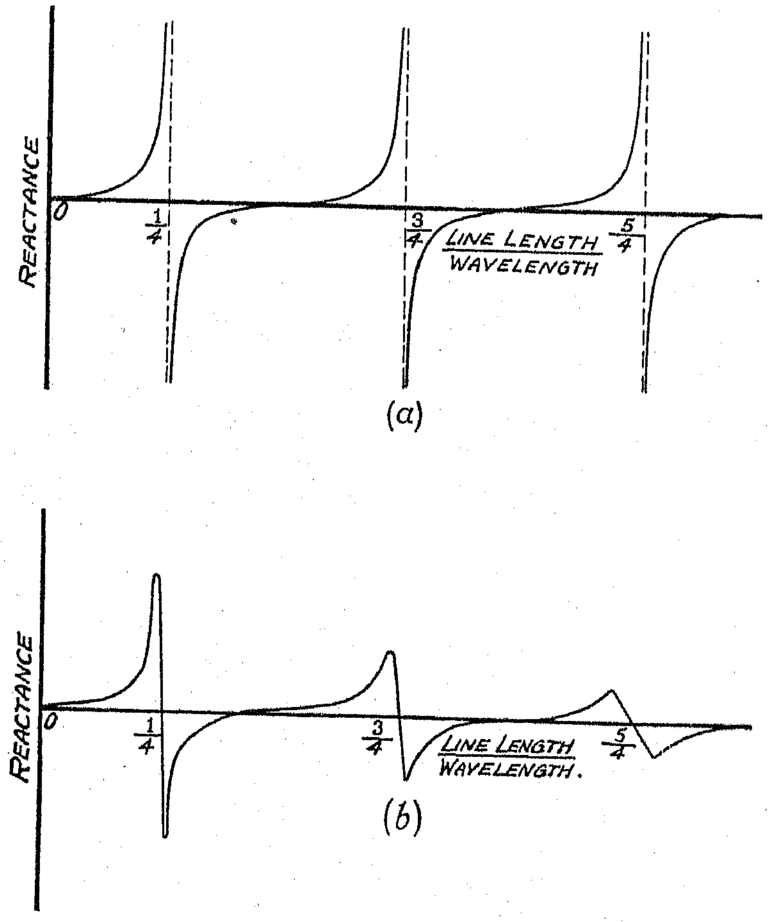

Fig. 3.—Variation of reactance of closed parallel-wire system with length.

(*a*) Line resistance zero.
(*b*) Line resistance high.

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* *Philosophical Magazine*, 1931, vol. 12, p. 843.

amplitude the density of space charge in the grid-anode space must be sufficient to form a virtual cathode near the anode. For any further increase in the space-charge density the virtual cathode moves nearer the grid and so decreases the electronic transit time in the grid-anode space.

The reactance X of a low-resistance parallel-wire system of length l short-circuited at its far end is given by the equation

$$X = Z_0 \tan \frac{2\pi l}{\lambda} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

in which Z_0 is the characteristic impedance of the line and λ the wavelength at which the reactance is measured.

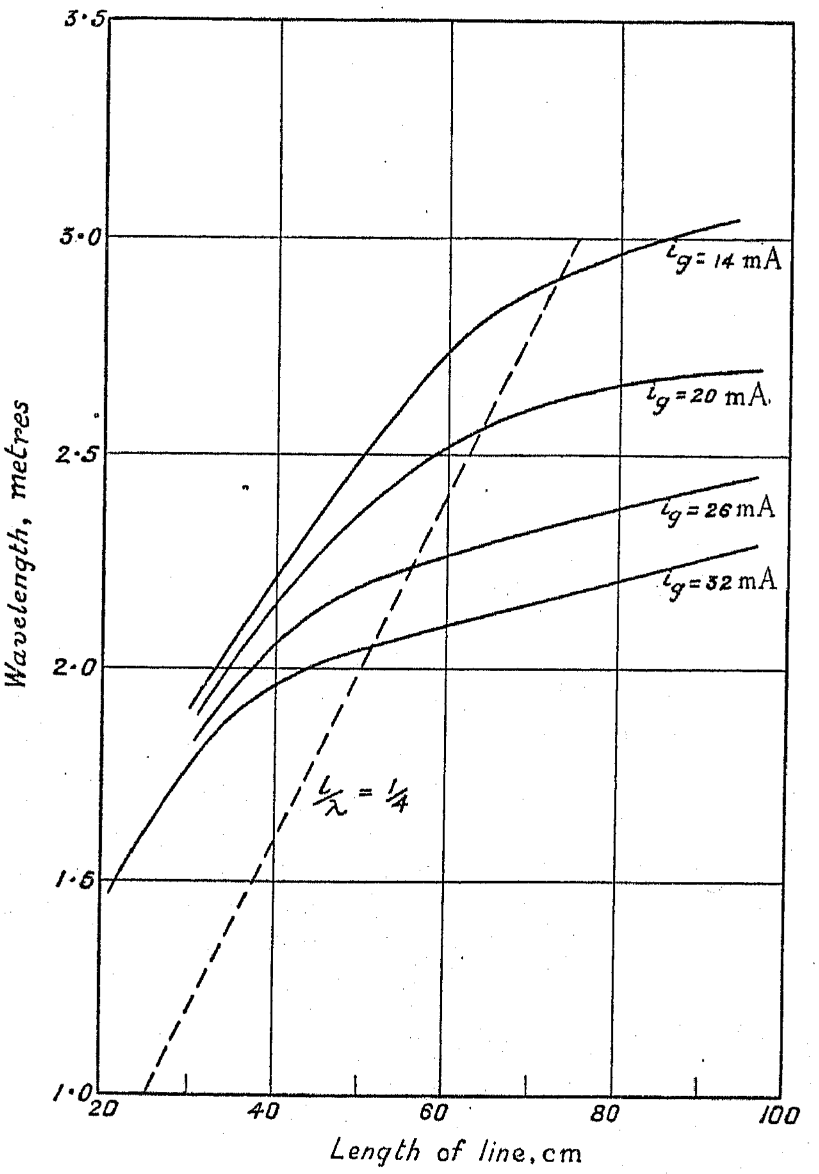

Fig. 4.—Relation between wavelength and length of parallel-wire system for split-anode triode, for various values of grid current (V_g = 60 volts).

The reactance X may be expressed as that of a capacitance C. The magnitude of this capacitance is then given by

$$C = -\frac{\lambda}{2\pi c X}$$
$$= -\frac{\lambda}{2\pi c Z_0} \cot \frac{2\pi l}{\lambda} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

in which $c = 3 \times 10^{10}$ cm per sec. Relation (4) has been used to determine the effective capacitance of the external circuit corresponding to various points along the second lowest experimental curve in Fig. 4. The results are given in Fig. 5, in which the dotted line passing approximately through the mean of the experimental points shows that the capacitance of the external circuit increased from negative values through zero (corresponding to the resonance condition) to positive values as the wavelength increased. The total reactance of the circuit and valve must be zero under all conditions. This means that the valve capacitance must change in the opposite manner to that of the circuit and must, therefore, be given by the full line in Fig. 5. It must be remembered that the valve capacitance determined in this way includes that between the tips of the anode segments, and various other incidental capacitances to earth. The operating conditions remained constant throughout the experiment from which the valve capacitance has been determined. Fig. 5 shows, therefore, that for such conditions the valve capacitance decreased from positive values at wavelengths less than that corresponding to resonance, through zero at resonance, to increasing negative values as the wavelength of the oscillations increased. This experimental result will be considered further in Section (4), in which a comparison is made between electronic oscillations and those obtained in magnetrons.

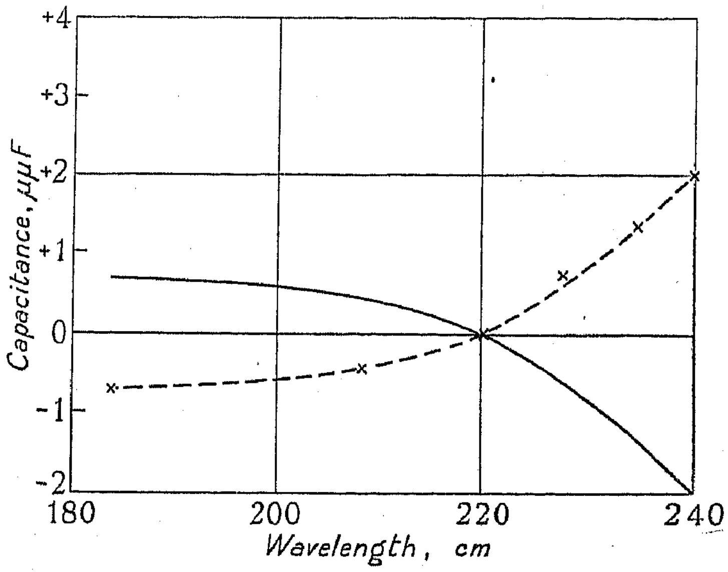

Fig. 5.

– – – – Effective capacitance of external circuit.
——— Effective capacitance of electronic oscillator.

The so-called Barkhausen–Kurz oscillations correspond to the upper portions of the experimental curves in Fig. 4, for which the wavelength of the oscillations is practically independent of circuit length. The Gill–Morell oscillations, on the other hand, are represented by the other parts of the curves. There is no real distinction between the oscillations other than that one type occurs at wavelengths greater than that for resonance within the valve, and the other at smaller wavelengths. The intensity of oscillation is greatest over the lower wavelength range; in fact, for any curve such as those given in Fig. 4 it will be found that the intensity of oscillation is usually greatest at the shortest wavelength generated for given operating conditions of the valve, and that the intensity gradually decreases as the wavelength increases owing to, say, increase in circuit length. There is one characteristic feature of these oscillations by means of which it can readily be determined whether the wavelength is greater or less than that for valve resonance. If on tuning an absorption wavemeter coupled to the oscillator the anode current increases the wavelength is greater, and if it decreases it is less, than that for resonance.

(c) Dependence of Oscillation on Circuit Connections

The experiments were repeated with the split-anode valve but with the external circuit connected in turn between the anode and filament and anode and grid. As pointed out above, the leads to the electrodes within the valve form in these cases appreciable parts of the external circuit. Although the total equivalent length of circuit cannot, therefore, be determined, the effect of a change in its length can still be observed. The results obtained under the above two circuit conditions for a grid potential and grid current of 60 volts and 30 mA respectively are shown in Fig. 6. It will be noted that the wavelengths were less when the circuit was connected between the anode and grid, but that—from a comparison with Fig. 4 in each case—they were appreciably less than those obtained when the circuit was between the two anode segments.

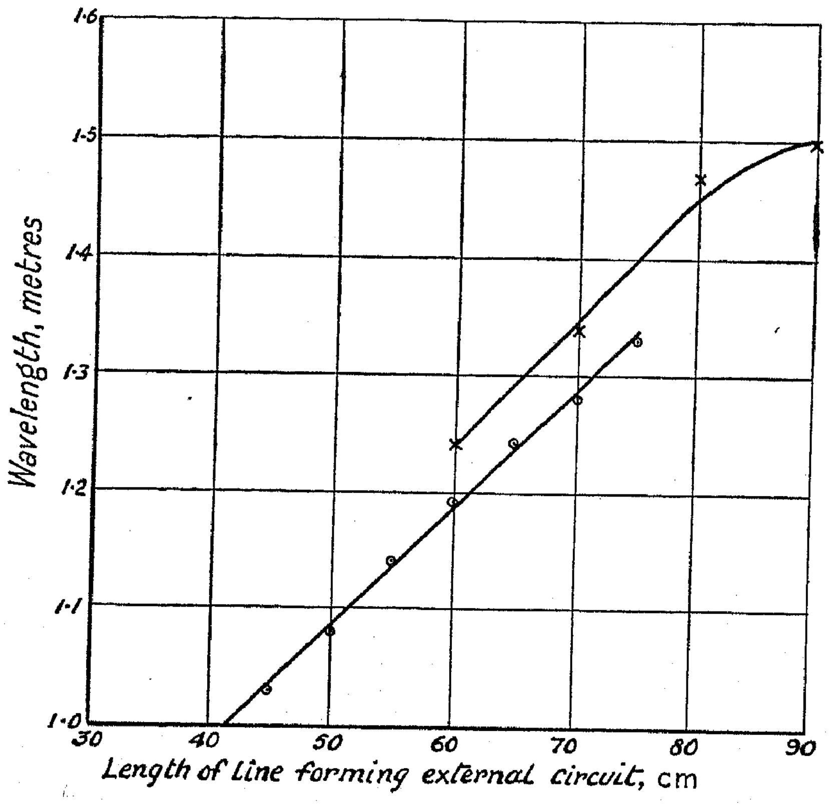

Fig. 6.—Dependence of wavelength on connections to external circuit. Grid voltage 60 volts, grid current 30 mA.
—o—o—o External circuit between grid and anode.
—x—x—x External circuit between filament and anode.

The experiments were repeated with an AT40 valve, which has the same electrode dimensions as the split-anode valve used above but has a full cylindrical anode. The results obtained were similar to those shown in Fig. 6, for the same conditions.

The period of any vibratory motion of individual electrons within the split-anode and AT40 types of valve must be the same for the same electrode potentials. The results described above show, however, that the wavelength of the electronic oscillations obtained with either type of valve depends on the electrodes across which the external circuit is connected, the wavelength increasing in general for given electrode potentials with increase in the distance between those electrodes. These two results indicate that the electronic oscillations cannot be due solely to the vibratory motion of electrons arising from the steady potentials applied to the electrodes. On the other hand, as the wavelength is found to be inversely proportional to the average velocity of the electrons and also proportional to the distance between the electrodes across which the external circuit is connected, the oscillations appear to be due to the finite time of transit of the electrons between the various electrodes of the valve, the wavelength in any particular case being proportional approximately to the time of transit between those electrodes which are connected to the external circuit. These conclusions are in agreement with those previously arrived at by the author* from the results of experiments with inverted diodes.

(3) OSCILLATIONS IN MAGNETRONS

(a) General

The full-line curve in Fig. 7 shows the usual manner in which the anode current in a magnetron varies with axial magnetic-field intensity for a given anode potential. Sometimes, however, the anode-current/magnetic-field characteristic is of the form shown by the broken line.

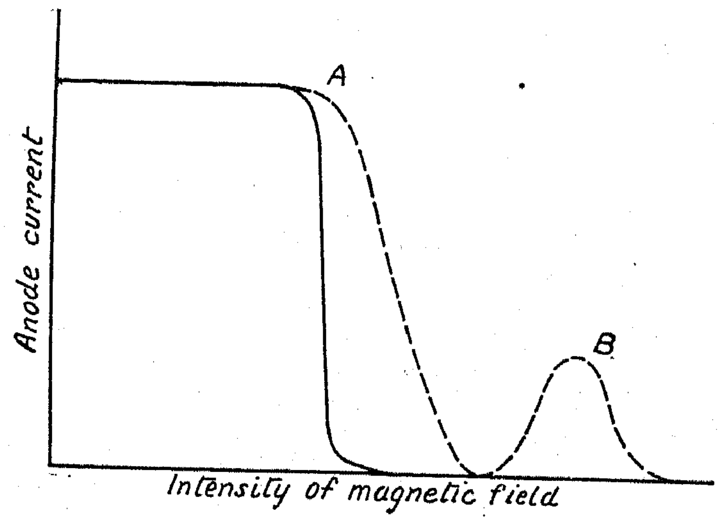

Fig. 7.—Variation of anode current in magnetron with magnetic field.

In such a case it is found that oscillations are produced for the conditions indicated by the region B, while, in addition, oscillations are also possible near the " cut-off " point A of anode current. The usual interpretation† of the results found with magnetrons is that the oscillations at the " cut-off " point are of an electronic form related in frequency to the electron velocity within the valve, while those found at greater field intensities are due to the production of a pure negative-resistance condition having no frequency discrimination.

An extensive experimental study has been made of the conditions under which oscillations are produced in magnetrons. In one experiment with a split-anode valve a Lecher-wire system was connected between the anode segments and, for various lengths of this type of circuit, the magnetic field intensity was adjusted for maximum oscillation amplitude. The results obtained for an anode voltage of 1 000 volts* are given in Fig. 8, in which the wavelength of the oscillations is plotted against the corresponding length of the Lecher-wire system as abscissa. As would be expected, the wavelength increased in general with increase in circuit length. It will be noted, however, that, for a given line length, there were under certain conditions more than one wavelength possible for the oscillations. These different forms of oscillation were usually not co-existent, since for the given anode voltage the intensity of the magnetic field was found to be approximately proportional to the wavelength of the oscillations. This characteristic is shown

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* *Philosophical Magazine*, 1935, vol. 19, p. 501.

† E. C. S. Megaw: *Journal I.E.E.*, 1933, vol. 72, p. 326.

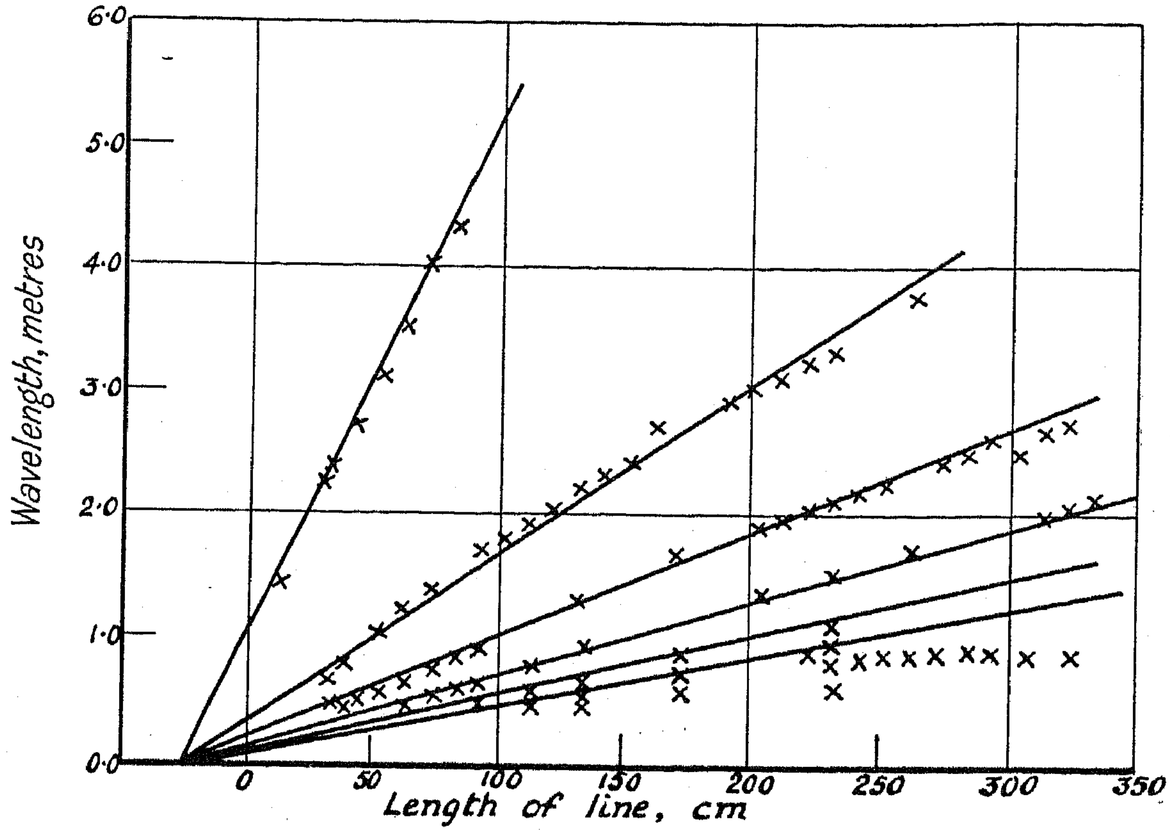

Fig. 8.—Relation between wavelength and length of Lecher-wire system, for a magnetron.

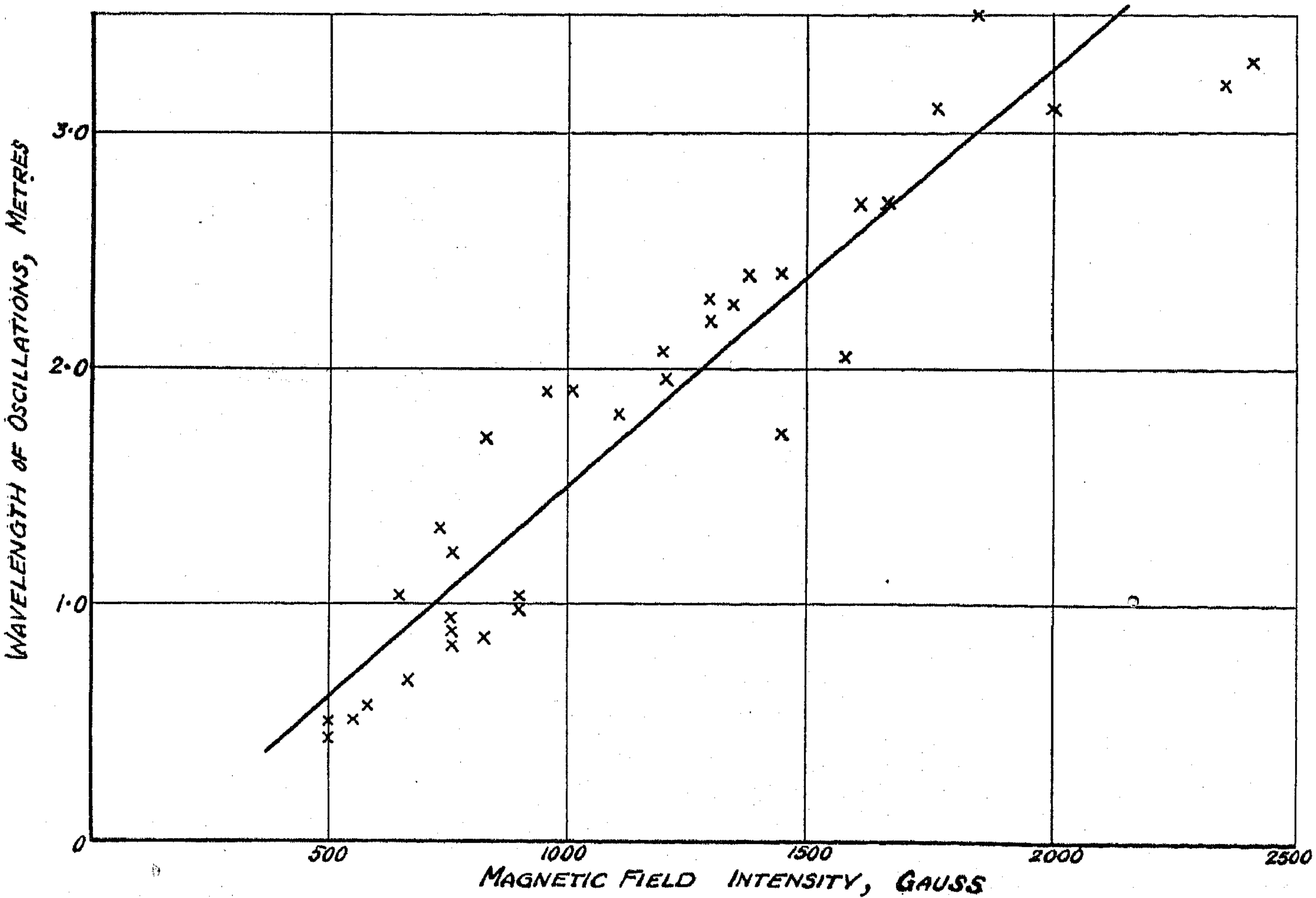

Fig. 9

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* The valve used in this experiment was actually of the 4-anode segment type having opposite segments connected.

in Fig. 9. In order to obtain oscillations of a required frequency by means of a magnetron, therefore, both the circuit and the magnetic field intensity must be adjusted suitably.

The two curves in Fig. 10 show the manner in which the magnetic field must be changed for two anode potentials (300 and 600 volts) at a series of wavelengths. In addition to the field required being proportional to the wavelength of the oscillations, it is clear from these two curves that it is also proportional to the anode potential.

It is well known* that the greatest intensity of oscillation is sometimes obtained when the direction of the magnetic field makes a small angle, known as the tilt, with the electrode axis of the magnetron. Fig. 11 shows the experimental results obtained with a split-anode magnetron between the segments of which three circuits, each consisting of an inductance coil in parallel with a capacitance, and resonating at 2·4 m, 4·9 m, and 12·5 m respectively, were connected in turn. The field for maximum oscillation intensity, as determined by the current induced in a small aperiodic circuit coupled loosely to the magnetron, was determined for various angles of tilt at a constant anode voltage of 600 volts. It will be seen that for each angle the field increased as the wavelength increased, but that for each wavelength the field for maximum oscillation intensity decreased with increase in the angle of tilt. The results indicate that with relatively small field intensities long-wavelength oscillations may be produced simply by rotating the valve axis with respect to the direction of the magnetic field. This effect was demonstrated in an experiment in which a Lecher-wire system which has pronounced overtone resonances was used as the external circuit. The length of the wires was adjusted so that their fundamental wavelength was in the region of 10 metres, the first overtone [$X = \infty$, relation (3)] occurring, therefore, at 3·3 metres. With a low magnetic-field intensity and zero tilt angle, the 3·3-metre oscillation alone was obtained. On rotating the valve axis with respect to the field, however, the 10-metre wavelength oscillation was also obtained.

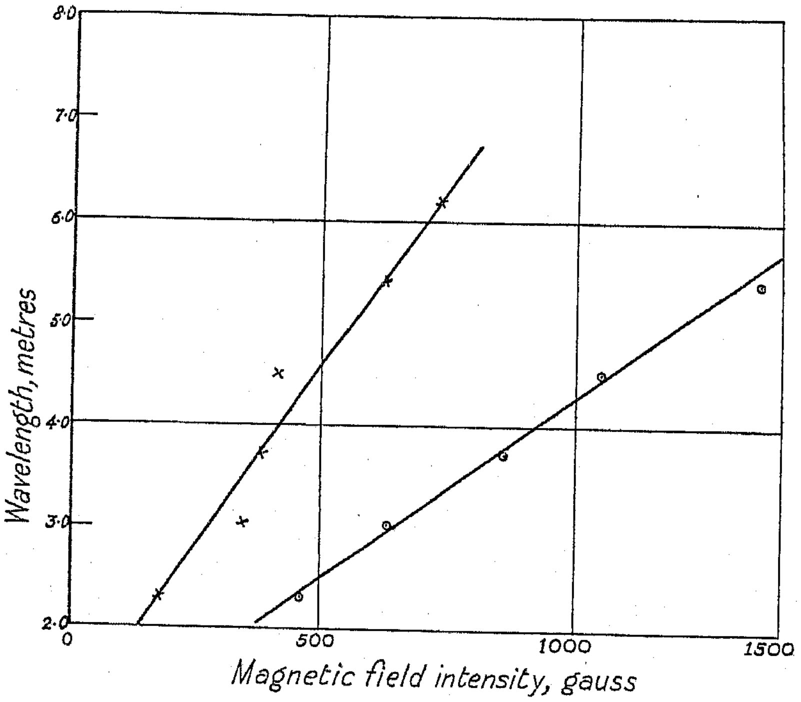

Fig. 10.—Relation between wavelength and magnetic field intensity for a split-anode magnetron, for two anode voltages.

⊙ ⊙ ⊙ Anode voltage = 600 volts.
× × × Anode voltage = 300 volts.

(b) Measurement of the Impedance of Magnetrons

(i) Experimental procedure.

The results described above suggest that oscillations corresponding to relatively long wavelengths may be produced by magnetrons, provided intense magnetic fields or low anode potentials are used. The great advantage in obtaining low-frequency oscillations is that a direct measurement of valve impedance may be made by a standard method* of measuring reactance and resistance at radio frequencies.

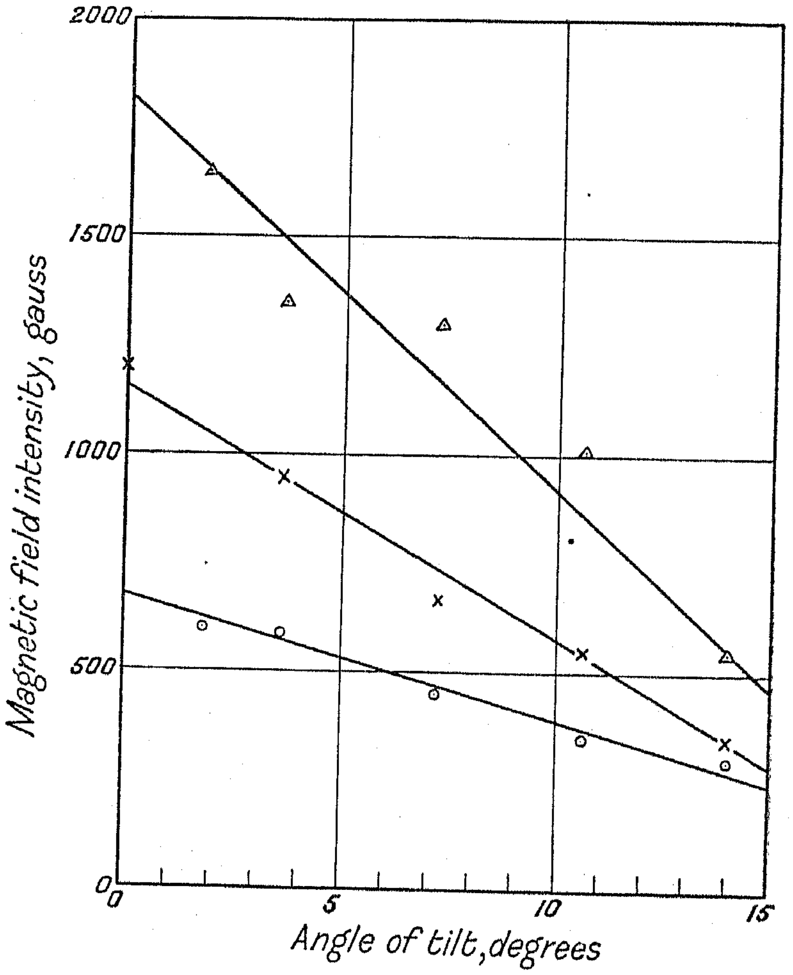

Fig. 11.—Relation between field-intensity and angle of tilt of field for maximum output from magnetron oscillator (2-segment anode).

△ △ △ Wavelength = 12·5 m.
× × × Wavelength = 4·9 m.
⊙ ⊙ ⊙ Wavelength = 2·4 m.

If the capacitance of a resonant circuit which is coupled inductively to the coil of a valve oscillator is varied, the frequency of the oscillator changes in the manner shown in Fig. 12. It can be shown that the radio-frequency resistance R of the coupled circuit, when that circuit is regarded as a resistance in parallel with a reactance, is given by

$$R = \frac{1}{\pi f \Delta C} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

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* A. A. Slutzkin and D. S. Steinberg: *Annalen der Physik*, 1929, vol. 1, p. 658.

* F. M. Colebrook and R. M. Wilmotte: *Journal I.E.E.*, 1931, vol. 69, p. 497.

in which ΔC is the difference in the capacitance in the coupled circuit corresponding to the points A and B in Fig. 12 for maximum and minimum oscillator frequencies, and f is the frequency of the oscillator in the absence of the coupled circuit. The central condition between A and B, for which the oscillator frequency (f_0, Fig. 12) is not altered by the frequency of the coupled circuit, occurs when the resonant frequencies of that circuit and the oscillator coincide. It is given very approximately by the mean capacitance between A and B. To use this method for the experimental analysis of a circuit at radio frequencies, a second oscillator is required in order to determine the appropriate frequency-changes. The second oscillator is adjusted so as to give an audio-frequency beat note with the first oscillator, and changes in this beat frequency are observed. In order to reduce the undesired coupling between this second oscillator and the circuit under test, it is usual to arrange the second oscillator to beat with a harmonic of the first oscillator.

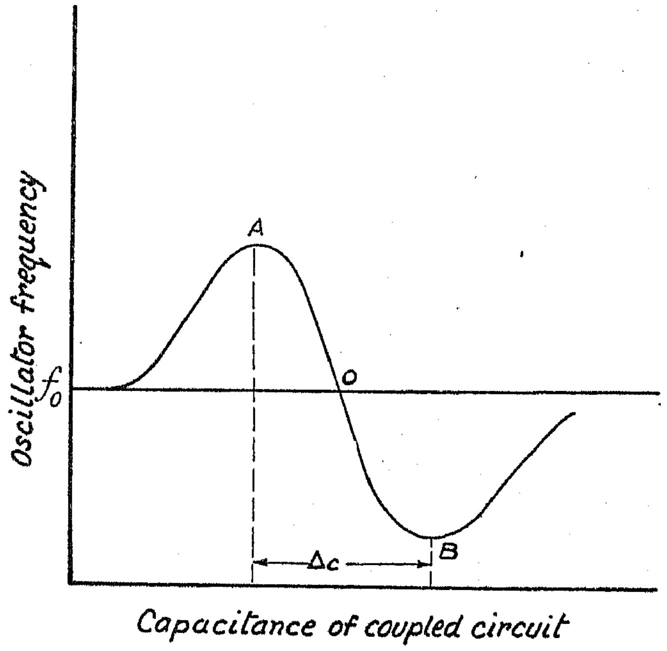

Fig. 12

A circuit consisting of an inductance and variable calibrated condenser of suitable magnitudes was measured in the above manner, the capacitances required for maximum and minimum beat frequencies being noted. The circuit was then connected between the segments of the split-anode magnetron whose impedance was required, the anode supply to the valve being connected at the centre of the inductance. The capacitances required for the appropriate beat frequencies were again observed, both with and without the filament heated, for a series of values of axial magnetic-field intensities. The variation in valve capacitance with magnetic field intensity was determined for a series of values of field from the change in the mean value of the two capacitances for maximum and minimum beat frequencies from that observed with the circuit alone. The effective parallel resistance of the valve and circuit was found at the same time, by measuring the difference ΔC [relation (5)] between the capacitances for maximum and minimum beat frequencies. As the parallel resistance of the circuit was determined before connection to the valve, the effective resistance of the magnetron for each value of field was readily obtainable from relation (5).

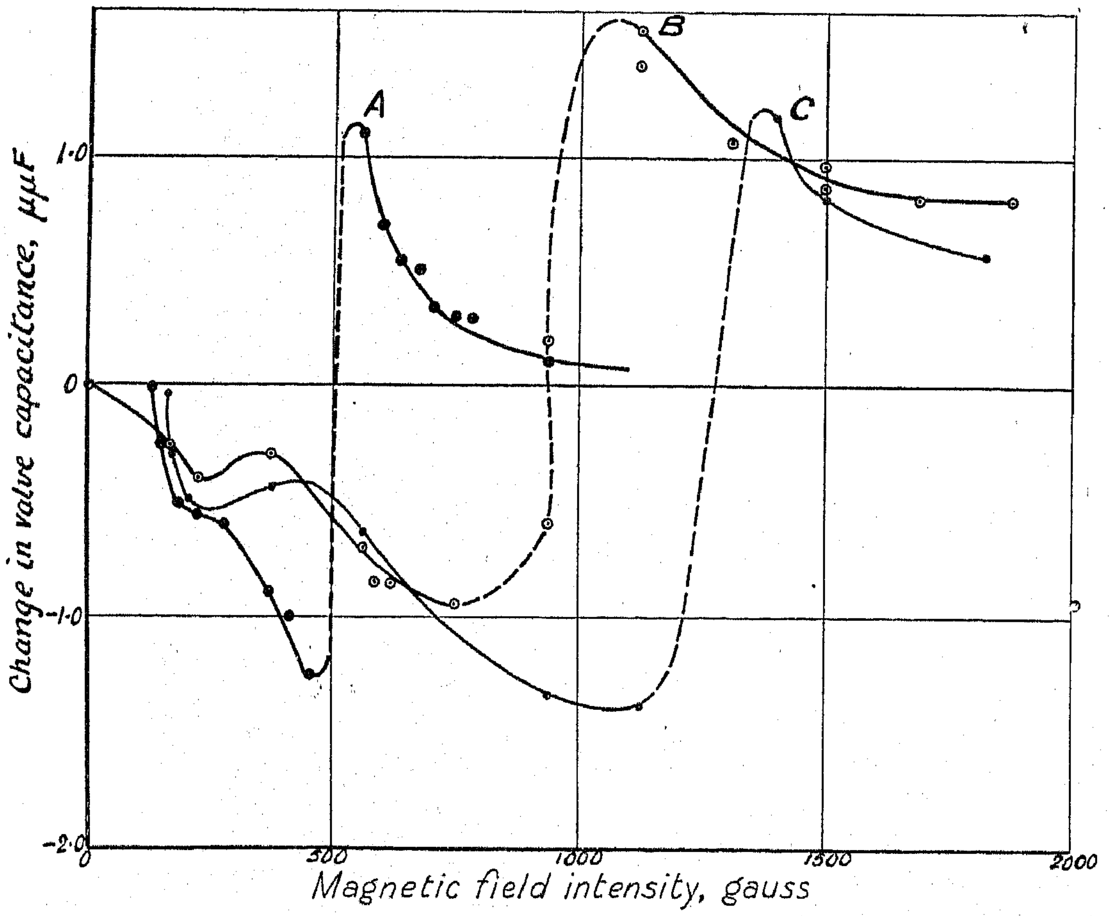

Fig. 13.—Relation between capacitance of magnetron and magnetic field intensity at wavelengths (A) 20 m, (B) 30 m, (C) 40 m. Anode voltage 120 volts, filament current 4/5 amps.

(ii) Experimental results.

The changes in effective valve capacitance with magnetic field intensity observed in the above way for a

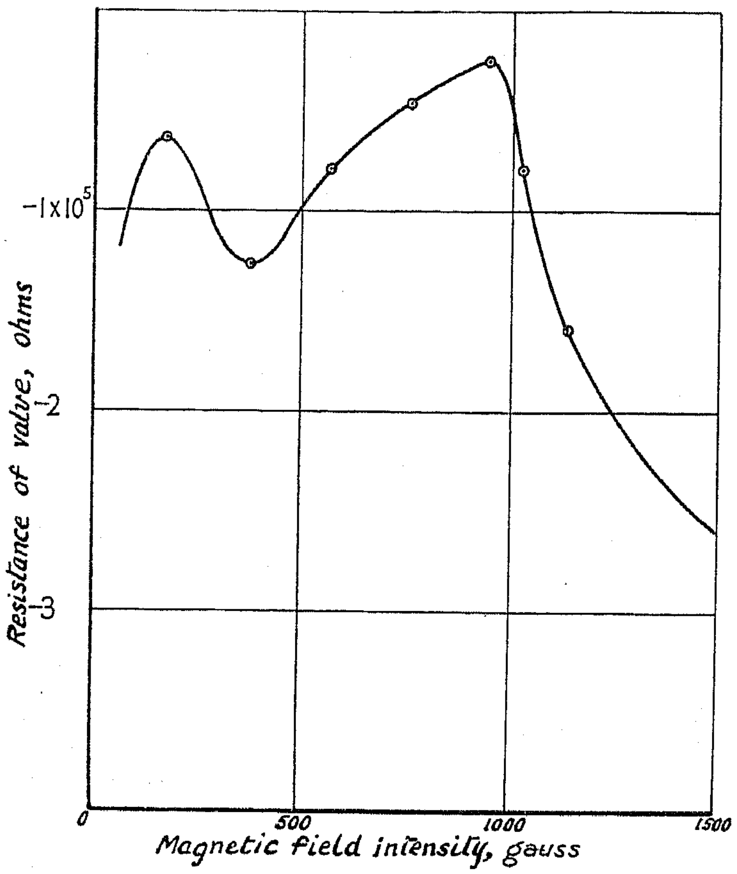

Fig. 14.—Variation of resistance between segments of magnetron with magnetic field intensity, at a wavelength of 30 m.

split-anode magnetron (anode voltage 120 volts) measured at wavelengths of 20, 30, and 40 metres, are given by the three curves in Fig. 13. In each case, as the magnetic field was increased, the valve capacitance decreased to a minimum value. Oscillations were obtained near these minimum-capacitance conditions, and persisted over the dotted portions of the curves. In the regions of oscillations an estimate of valve capacitance was obtained by determining the condition under which zero beat frequency was obtained between the magnetron and the first test oscillator. On further increase in magnetic field the oscillations ceased near a maximum valve-capacitance condition, from which the valve capacitance decreased asymptotically to a value slightly greater than its original value on further increase in field. It will be observed that the fields for the various regions of oscillation were approximately proportional to the wavelengths of these oscillations.

The corresponding variation in the resistive component of the inter-segment impedance is given in Fig. 14. The curve in this figure represents the results obtained at a wavelength of 30 metres, but it is similar in form to those observed at the other wavelengths. The resistance was negative over a wide range of magnetic field intensities, but had two conditions for minimum value, that occurring at greater field intensity being always less than that at the lower field. By suitable adjustment of filament current, oscillations were limited to a region near the minimum negative-resistance condition.

The curves in Fig. 15 give the valve-capacitance variation with magnetic field obtained at a wavelength of 20 metres, for anode voltages of 60, 120, 240, and 300 volts. The regions over which oscillations were produced are shown by the positions for which rapid varia-

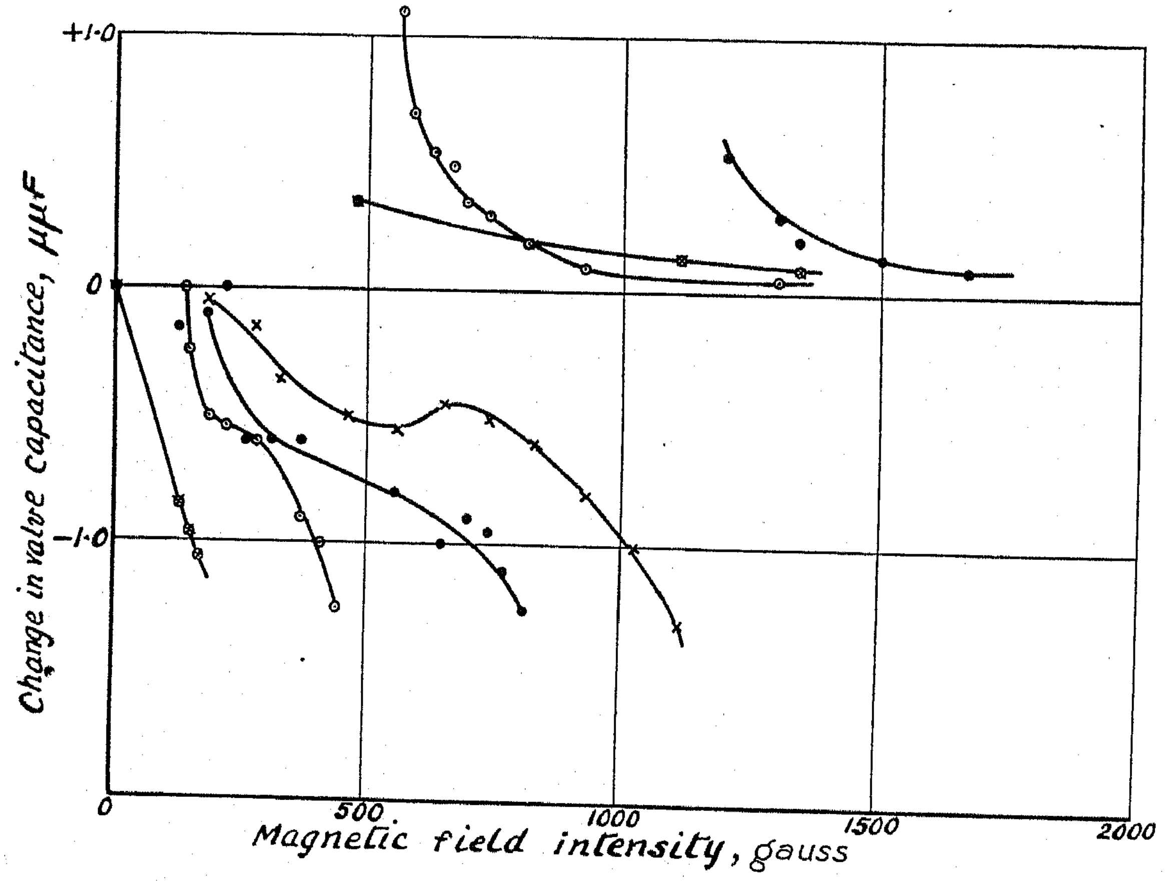

Fig. 15.—Relation between capacitance of magnetron and magnetic field intensity for various anode voltages at a wavelength of 20 m.

⊕ ⊕ ⊕ Anode voltage = 60 volts.
○ ○ ○ Anode voltage = 120 volts.
● ● ● Anode voltage = 240 volts.
× × × Anode voltage = 300 volts.

tions of valve capacitance were obtained. It will be seen that the magnetic field required for oscillations of 20 metres wavelength increased with increase in anode potential, so that the ratio of magnetic field to anode potential remained approximately constant.

The above results were obtained with the external circuit connected between the segments of a 2-anode-segment magnetron. When a 4-anode-segment valve was used, the electrode dimensions being the same as

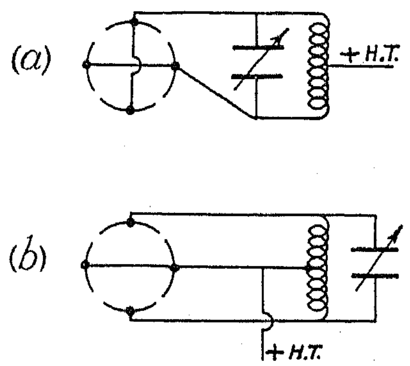

Fig. 16.—Circuit connections to 4-anode-segment magnetron.

those of the previous valve, and the external circuit connected as shown in Fig. 16(*a*), the valve-capacitance variation measured at a wavelength of 30 metres for anode voltages of 60 and 120 was as shown in Fig. 17. Comparison between the curve in Fig. 17 for an anode potential of 120 volts and the results obtained for the same wavelength and anode potential for the 2-segment valve (curve B, Fig. 13) shows that the magnetic field required for the production of oscillations of a given wavelength for the 4-segment valve was approximately twice that in the case of the 2-segment valve of similar dimensions and the same electrode potentials. When, however, the external circuit was connected to the 4-anode-segment valve as shown in Fig. 16(*b*), the results were identical with those obtained for the 2-anode-segment valve.

No appreciable variation in valve capacitance with change in magnetic field intensity was observed in any of the above experiments without the occurrence of oscillations in the central region of that variation. For a given anode potential neither valve-capacitance change nor oscillations were obtained for low filament currents. This condition persisted as the filament current was increased in small steps until a critical value of filament current was reached, for which the required valve-capacitance change occurred accompanied by a narrow range of magnetic field intensity over which oscillations were also obtained. On further increase in filament current the valve-capacitance change persisted, but the region for oscillations widened. As measurements under oscillating conditions were difficult, the experiments were made with the lowest value of filament current required for the production of oscillations.

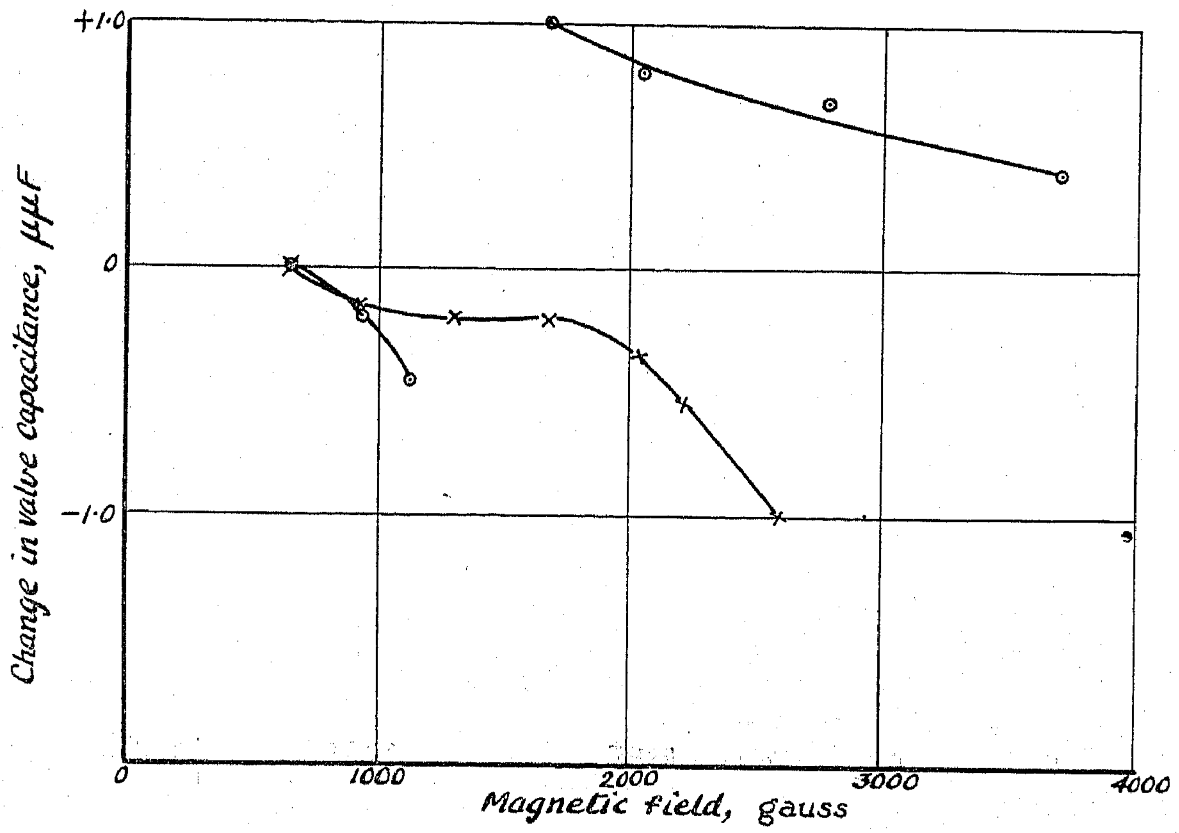

Fig. 17.—Relation between capacitance of 4-segment magnetron and magnetic field. Wavelength, 30 m.

⊙ ⊙ ⊙ Anode voltage = 60 volts.
× × × Anode voltage = 120 volts.

(iii) Analysis of results.

Oscillations occur in a resonant circuit containing resistance when a negative resistance less in magnitude than the effective parallel resistance of the circuit is connected across it. Fig. 14 shows that in a magnetron two conditions of low negative resistance are possible. One of these conditions occurs in the neighbourhood of the "critical" field at which, for the anode potential applied to the valve, the anode current varies rapidly with the magnetic field strength intensity; and the second at a field strength proportional approximately to the wavelength at which the measurement is made. The low negative resistance obtained near the "critical" field is apparently of the usual type met with in retroactive and dynatron types of oscillators. The second condition of low negative resistance is peculiar, however, in that its position depends on the wavelength of the measurement and also that it is associated with rapid changes in valve capacitance. This latter characteristic is brought out clearly in Fig. 18, in which the capacitance of a split-anode magnetron measured for an anode voltage of 120 volts at a series of wavelengths are combined so as to give the variation of valve capacitance with wavelength for various values of magnetic field. The type of capacitance-change for each curve is somewhat similar to that obtained for the dielectric constant of a dispersive medium at about its natural frequency. This suggests that the second low-resistance condition in the magnetron is accompanied by, or even due to, some resonance effect occurring within the valve.

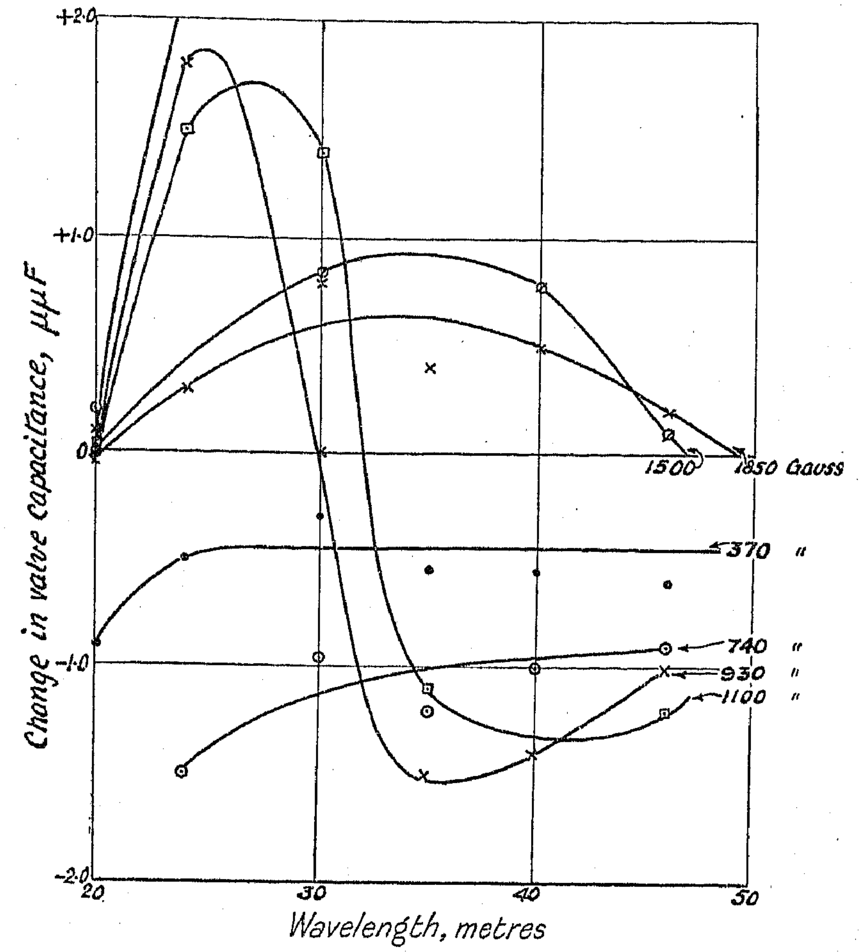

Fig. 18.—Relation between valve capacitance and wavelength, for various magnetic fields. Anode voltage, 120 volts.

The object of any future analytical investigation of the magnetron as a short-wave oscillator will be to determine its equivalent electrical circuit. The experimental results obtained above can readily be reduced so as to show the component impedances required of such a circuit. Two types of electrical circuits having resonances are possible, namely series and parallel. As the measurements made above reduced the impedance of the magnetron to that of a capacitance in parallel with a resistance, both of those types of circuit will be reduced to that form.

Consider the circuit shown in Fig. 19 (inset), consisting of an inductance L, a capacitance C, and a resistance R, all in parallel. This circuit is equivalent at a wavelength λ to that formed by the circuit having the capacitance C_e in parallel with the resistance R, if

$$C_e = C\left[1 - \left(\frac{\lambda}{\lambda_0}\right)^2\right] \quad . \quad . \quad . \quad . \quad (6)$$

where λ_0 is the resonant wavelength of the circuit LC. The manner in which C_e varies about the resonant wavelength λ_0 is shown by the curve in Fig. 19. Although the sense of the change in equivalent capacitance about λ_0 is the same as that found (Fig. 18) for the magnetron, the magnitude of that variation is different. This is particularly evident at wavelengths near resonance. The electrical circuit equivalent to the magnetron, therefore, cannot be of the ordinary form consisting of an inductance, capacitance, and resistance in parallel.

The series circuit shown in Fig. 20 (inset) is equivalent to the capacitance C_e in parallel with the resistance R_e when

$$C_e = \frac{-C\left[\left(\frac{\lambda_0}{\lambda}\right)^2 - 1\right]}{\frac{4\pi^2c^2R^2C^2}{\lambda^2} + \left[\left(\frac{\lambda_0}{\lambda}\right)^2 - 1\right]^2} \quad . \quad . \quad (7)$$

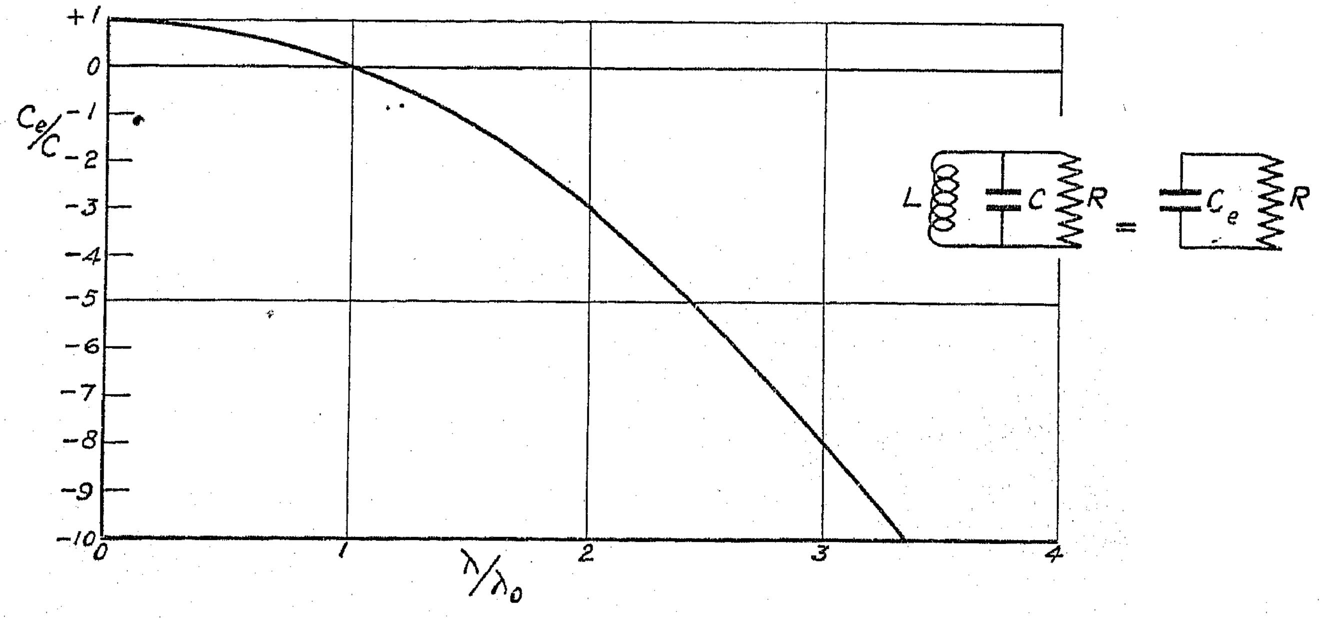

Fig. 19.—Variation with wavelength (λ) of equivalent capacitance (C_e) about resonant wavelength (λ_0).

and

$$R_e = R + \frac{\lambda^2\left[\left(\frac{\lambda_0}{\lambda}\right)^2 - 1\right]^2}{4\pi^2c^2C^2R} \quad . \quad . \quad . \quad . \quad (8)$$

in which c is the velocity of light.

The variation of C_e about λ_0 is shown diagrammatically in Fig. 20. The shape of this curve is very similar to that of those obtained (Fig. 18) for the magnetron, but, it will be noted, the equivalent capacitance of the ordinary series circuit is decreased or increased about the resonant wavelength in exactly the opposite way to the observed capacitance of the magnetron. It has been pointed out above that the parallel resistance of the magnetron impedance is negative over wide ranges of magnetic field intensity. The only method by which R_e in relation (8) can be made negative is to assume that the series resistance R is also negative. Change in the sign of this term in relation (8) does not, however, alter the parallel capacitance C_e so as to agree with the experimental results. If, on the other hand, the series capacitance C in relation (7) is assumed to have a negative value, the variation about the resonant wavelength of C_e is reversed. Actually, of course, in such an assumption the series inductance L must also be negative, because the algebraic values of both L and C must have the same sign in order to realize the resonant wavelength λ_0. The observed variation of impedance of a split-anode magnetron about the oscillating condition is similar, therefore, to that which would be obtained about the resonant wavelength by a series circuit consisting of a negative resistance, negative inductance, and negative capacitance.

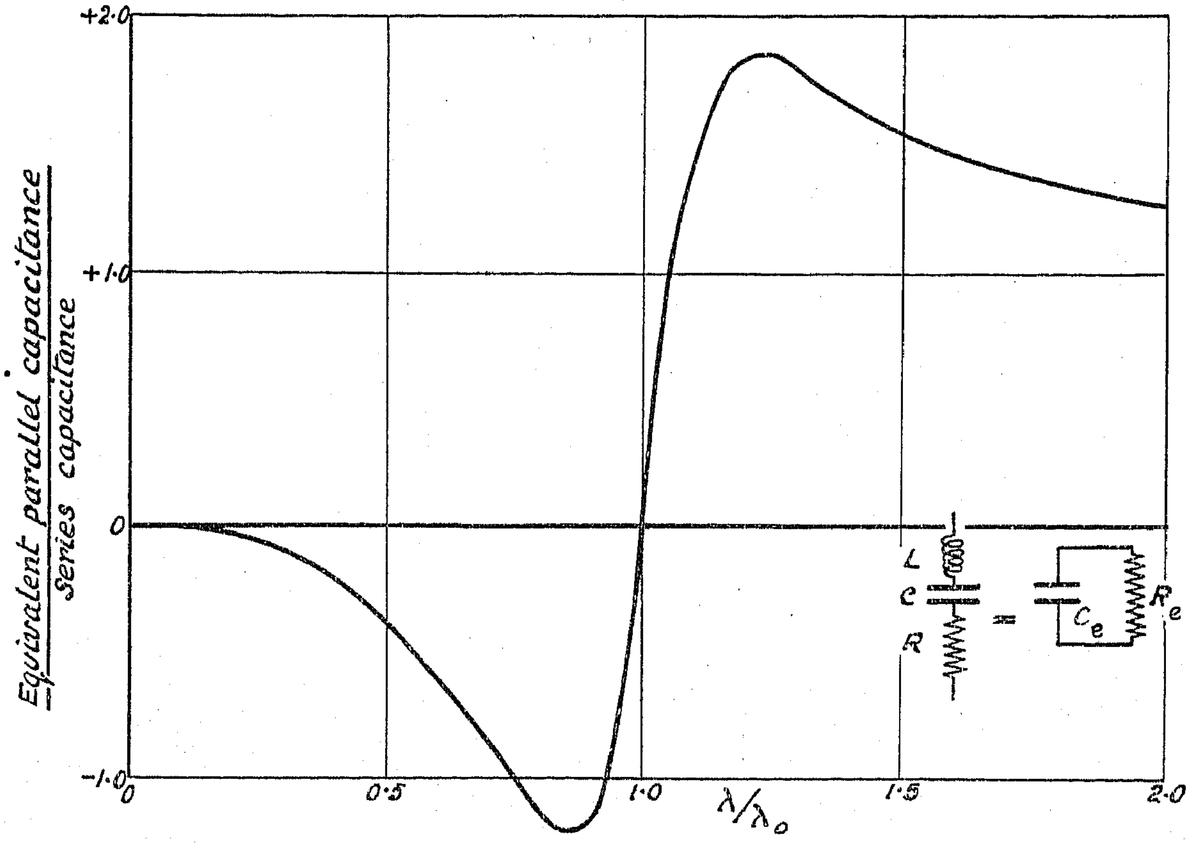

Fig. 20.—Variation with wavelength (λ) of equivalent parallel capacitance (C_e) about resonant wavelength (λ_0) of series circuit.

There is another point of resemblance in the behaviour of such a circuit and that of the magnetron. At wavelengths much greater than that corresponding to resonance the equivalent parallel capacitance C_e of the series circuit as given by relation (7) reduces approximately to that of the series capacitance C, while at short wavelengths it tends to zero. The difference in the equivalent parallel capacitance C_e of such a circuit measured at long and short wavelengths is therefore equal to the actual series capacitance in the circuit. This feature is shown diagrammatically in Fig. 20. The experimental curves in Fig. 18 for the magnetron show the same characteristic, but in this case the capacitance of the series circuit equivalent to the magnetron must have a negative magnitude. It will also be observed from these curves that as the magnetic field was increased for a given anode potential the negative valve capacitance also increased.

The experimental results obtained with the magnetron valves show, therefore, that the oscillations obtained at magnetic field intensities greater than the "critical" value were due to a resonance condition within the valve; also that oscillations did not occur without the simultaneous appearance of this resonance. The resonance has the features associated usually with a series electrical circuit, but the component impedances of the equivalent circuit must have negative magnitudes. These oscillations may therefore be called, for convenience, "resonance" oscillations, in order to distinguish them from those occurring near the "critical" field, which appear to be of the dynatron type and not associated with any marked variation in valve reactance.*

(4) COMPARISON BETWEEN "RESONANCE" OSCILLATIONS IN MAGNETRONS AND ELECTRONIC OSCILLATIONS

It was pointed out in Section (2) that electronic oscillations in positive-grid triodes occur in the neighbourhood of valve resonance; also the full-line curve in Fig. 5 shows that this resonance is such that the valve capacitance decreases from positive values at wavelengths less than that corresponding to resonance, to zero near resonance, and then to increasing negative values as the wavelength of the oscillations is further increased. The experiments with magnetrons indicate that the oscillations occurring at fields greater than the "critical" field are also associated with a valve resonance condition of the same type. The steep portions of the experimental curves given in Fig. 18 represent those regions over which oscillations were obtained with the split-anode magnetron. In this case it will be seen that the capacitance variation about the resonant wavelength is exactly the same as that obtained with the split-anode triode when used as an electronic oscillator. There are other similarities between the oscillations obtained in positive-grid triodes and magnetrons. Maximum oscillation intensity at a given frequency and for constant electrode potentials is obtained usually with a magnetron when the magnetic field is increased to the greatest value for which oscillations are produced. Reference to the curves in Fig. 13 shows that under this condition the valve has maximum effective capacitance. In the experiments with positive-grid triodes described above, maximum oscillation intensity was always obtained at approximately the shortest wavelength of the oscillations possible for the operating conditions of the valve. The full line in Fig. 5 shows that the valve capacitance of an electronic oscillator is a maximum near this minimum-wavelength condition. Maximum amplitude, therefore, is obtained, with both "resonance" oscillations in magnetrons and electronic oscillations in triodes, in the neighbourhood of the maximum valve capacitance.

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* The distinction between dynatron and resonance oscillations has also been pointed out by E. W. B. Gill and K. G. Britton (*Journal I.E.E.*, 1936, vol. 78, p. 461).

The beat frequency between a triode electronic oscillator and, say, a harmonic of a retroactive valve oscillator is more of the nature of a hiss than of a pure audio-frequency note. The poor wave-form indicated by this result appears to be a characteristic of all electronic oscillators. If the same experiment is repeated with a split-anode magnetron in place of the electronic oscillator it will be found that at the oscillating condition near the "critical" field the beat frequency obtained is relatively pure. On increasing the field until the condition for resonance oscillations at the same wavelength is reached, it will be noted that the beat frequency is no longer pure; in fact, it is very similar to that observed with the triode electronic oscillator. The difference between the audio-frequency beat notes obtained in this way for the dynatron and resonance types of oscillation was particularly evident in the case of a split-anode magnetron having the anode of mesh construction.

The similarity between the type of resonance, the poor wave-form, and the operating conditions, for the resonance oscillations in magnetrons and the electronic oscillations in positive-grid triodes suggests that these two types of oscillations are actually of the same form.

Electronic oscillations have already been found in magnetrons near the critical value of magnetic field intensity.* The wavelength of these oscillations is given, usually, as

$$\lambda_{\mathrm{cm}} = \frac{13\,000}{H_{\mathrm{gauss}}} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The value of the critical field H is, however, given by

$$H^2 = \frac{180V}{d^2} \quad . \quad . \quad . \quad . \quad . \quad (10)$$

in which V is the anode voltage and d is the diameter of the valve in centimetres.

Relations (9) and (10) can be combined to yield the result

$$\lambda = 72d^2\frac{H}{V} \quad . \quad . \quad . \quad . \quad . \quad (11)$$

The 2-segment magnetron used in the above experiments had an anode diameter of 1 cm, so that the wavelength of the electronic oscillations near the critical field would, from relation (11), be given by

$$\lambda = 72\frac{H}{V} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

The results given in Fig. 17 show that for the resonance oscillations the constant required in relation (12) is nearly 400. The reason for the large difference in the constant in relation (12) for the two types of oscillations may be due to the totally different electron paths under conditions equal to and much greater than the critical field. The important point to be noted, however, is that, apart from the difference in a constant term, the law governing the wavelength of the electronic oscillations in magnetrons is the same as that for the resonance type. As the latter have reactance variations similar to those of electronic oscillations in triodes, the conclusion is reached that resonance oscillations in magnetrons are essentially a form of electronic oscillation.

(5) HYPOTHESIS FOR THE OCCURRENCE OF ELECTRONIC OSCILLATIONS IN THERMIONIC TUBES

Electronic oscillations appear to be due in some way to the finite time of transit of electrons between the electrodes of the valve which is the source of the oscillations. This empirical result, combined with the detailed analysis given above of the impedance of an electronic oscillator (in the special case a magnetron), may be used to give a simple picture of the phenomena occurring within an electronic oscillator. Consider a diode having a cathode emitting electrons towards a positively charged anode. If an alternating e.m.f. is applied between the cathode and anode in series with a fixed potential, alternating current will flow across the valve. This current can be divided into two components—the displacement current due to the inherent capacitance of the diode, and a convection current. For simplicity the displacement current will be assumed to be small compared with the alternating component of the convection current. For low frequencies of the alternating e.m.f. applied to the diode, the response of the electronic current is instantaneous, but as the frequency is increased the anode current begins to lag on the anode potential owing to the finite velocity of the electrons within the valve. A rough pictorial representation of this simple case is given in

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* E. C. S. Megaw: *Journal I.E.E.*, 1933, vol. 72, p. 326.

Fig. 21. The vectors *E* and *I* represent the phases of the anode voltage and the current respectively for a relatively low frequency. As the frequency is increased the angle between *E* and *I* increases. While the current vector remains in the quadrant marked "*a*," Fig. 21, the diode is equivalent to an inductance in series with a positive resistance. If the frequency is increased further, the current vector moves in a clockwise direction into the *b* and then the *c* quadrant. The circuit equivalent to the valve is that of an inductance or capacitance in series with a negative resistance, according as the current vector lies in the *b* or *c* quadrant. The reactive component of the equivalent impedance changes sign, therefore, as the current vector passes from the *b* to the *c* quadrant; in other words, there is an apparent resonance. At frequencies a little lower than that corresponding to this resonance condition the valve reactance is positive, while at higher frequencies it is negative; that is, the valve capacitance is decreased or increased according as the frequency of the applied field is less or greater than that for valve resonance. This variation of valve capacitance about the resonance frequency agrees with that found both for the resonance oscillations in magnetrons and for the electronic oscillations in positive-grid triodes. The above hypothesis as to the conditions obtaining within an electronic oscillator can only be regarded as very crude, but it is of some interest that it gives a suggestion as to the reason why the finite velocity of electrons within a thermionic tube can give rise to a negative resistance and a reactance variation in accord with the experimental results described above.

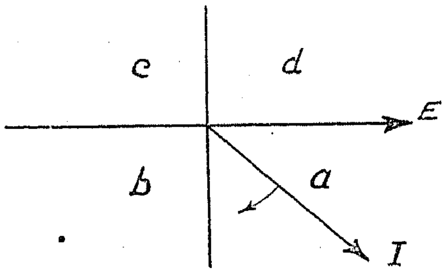


Fig. 21.—Vectorial representation of voltage and current in diode at high frequencies.

The above considerations indicate how the reactance variations of an electronic oscillator about its natural frequency may result as a consequence of the finite time of transit of the electrons between the electrodes of the valve. This effect is due really to the introduction of a lag of approximately π between current and voltage by the low electronic velocity. The type of resonance obtained in the case of the split-anode magnetron and, therefore, presumably of all electronic oscillators, is similar to those found for optically active media in the neighbourhood of absorption bands, except that the reactance and resistance variations are of opposite sign. This change in character between the two resonances could be accounted for if it were assumed that an ordinary series resonance as found in optical media occurred in an electronic oscillator but that, in addition, at some point there was a change of π in the phase difference between the current and voltage. Recent research work has shown a remarkable similarity to exist between the phenomena associated with a stream of electrons and those occurring in the path of an electromagnetic wave. Now an advance of phase occurs when an electromagnetic wave passes through a focus, the magnitude of the phase-shift being π or $\pi/2$ according as the wave is spherical or cylindrical. If such foci existed within an electronic oscillator, the reactance and resistance variation obtained experimentally could be explained as that due to an ordinary resonance of the same type as those observed in the neighbourhood of absorption bands in optical media, and one or two foci, according as the type of focus was of spherical or cylindrical form. It is to be noted that the retarding field in the grid-anode space of a positive-grid electronic oscillator is of the type necessary for the formation of a focus near the anode of the valve. Crossed electric and magnetic fields as used in a magnetron are also well known as devices for focusing electron beams. Whether foci are formed within electronic oscillators or are a necessary condition for the production of these oscillations requires further investigation.

(6) CONCLUSIONS

The experimental analysis given above may conveniently be summarized as follows:—

(*a*) The periodic time of the electronic oscillations produced in a thermionic tube is proportional approximately to the time of transit of the electrons between the two electrodes across which the external circuit is connected.

(*b*) Electronic oscillations of relatively long wavelength are obtained with the split-anode type of magnetron at magnetic field intensities greater than the critical field.

(*c*) The wavelength of the electronic oscillations in magnetrons is proportional to the ratio of the magnetic field intensity to the anode potential.

(*d*) Electronic oscillations are associated with a valve resonance condition.

(*e*) The equivalent electrical circuit of an electronic oscillator is of the series type but has negative inductive, capacitive, and resistive, component impedances.

(*f*) Maximum oscillation intensity is obtained from an electronic oscillator at the wavelength lower than that for valve resonance at which the valve has minimum capacitive reactance.

(*g*) The wave-form of electronic oscillations is, in general, poor.

(*h*) Oscillations of the ordinary dynatron type and of relatively good wave-form are obtained with magnetrons near the critical field.

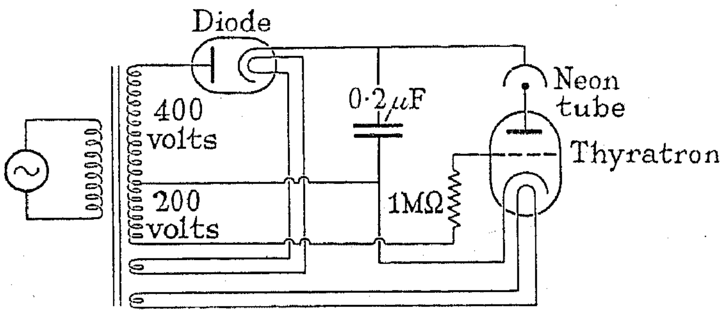
Acknowledgments

The work described in this paper has been carried out as part of the programme of the Radio Research Board, and acknowledgment is due to the Department of Scientific and Industrial Research for granting permission for publication. The author is also indebted to Dr. R. L. Smith-Rose for advice on the method of presentation of the paper, and to Mr. A. C. Gordon-Smith for assistance in the experimental work.

DISCUSSION ON
"A THYRATRON STROBOSCOPE"*

Mr. A. Glynne (*communicated*): The stroboscope is to be used to observe the difference in frequency between a supply of standard frequency and the speed of rotation of a machine. An ultra-short flash has no advantage for this purpose. If a small neon tube be supplied with 120 volts (d.c.) together with about 40 volts of the standard frequency (a.c.), the tube will give flashes of 3 or 4 milliseconds duration. If the image of the tube be now examined in a flat mirror attached to the end of shaft of the machine at a small angle to the plane of rotation, the slip speed may conveniently be observed in daylight. The load on the a.c. supply is of the order of 0·005 volt-ampere, i.e. less than 1 per cent of that mentioned in the paper.

In the author's stroboscope the rate of change of the flux in the transformer core is reduced by the secondary ampere-turns and by the eddy currents in the iron. The circuit shown in the Figure avoids this effect, requires only an a.c. supply, and is not subject to the troubles mentioned in the paper. In operation the condenser charges up to the peak value of the a.c. potential during the first half of the positive half-cycle. Nearly 90° later the negative potential on the grid of the thyratron becomes sufficiently reduced to allow the condenser to discharge through the neon tube. As there is no inductance in this circuit and very little resistance, the discharge is very rapid. I estimated the duration of the flashes, using the method described below, to be about 10 microseconds.



I should like to know how much current is taken from the d.c. supply in the author's apparatus. Suppose that it is 30 milliamperes and that the discharge through the thyratron takes place in 50 microseconds; this would give a peak value of current in the thyratron in excess of 12 amperes. It is well known that the cathodes of these tubes can easily be damaged in this way. The difficulty can be avoided by using a mercury valve with a mercury-pool cathode. I have tried, with success, using, in place of the thyratron, one anode, one grid, and the cathode of a mercury-arc rectifier. In one experiment the a.c. voltage was raised to 620, the condenser was reduced to 0·03 μF, and the mean current was 4 milliamperes. The neon tube used was of the "bee hive" type without resistance, and its light illuminated the edge of a disc moving at 2 500 cm per sec. The apparent thickening of radial lines 0·25 mm wide was estimated to be 50 per cent, which gives the duration of the flashes as 5 microseconds. If a phase-shifting transformer be used to supply the alternating current to the apparatus, the operation of any machinery running at synchronous speed can be studied.

Mr. R. S. J. Spilsbury (*in reply*): With regard to Mr. Glynne's first suggestion, it appears that the total input to the circuit would be of the order of 0·02 volt-ampere, or about 1/500th of that taken by the device described in the paper, so that the light given is presumably very feeble: this feature greatly reduces the utility of a stroboscope. As to the power demand, it should perhaps be emphasized that the load imposed by my device on the controlled-frequency supply is due practically entirely to the resistor R_3: if the supply is taken from an output transformer, R_3, C_3, and C_4 can be omitted, when the consumption is merely that of the thyratron grid circuit and is extremely small.

Mr. Glynne's second circuit, shown in the figure, is similar in principle to mine, but it employs a rectified a.c. supply instead of d.c. mains and omits the induction coil. It would be of no use for my purpose, since it takes the whole of the power for the neon lamp from the controlled-frequency source: it might, however, have advantages for applications for which the mains frequency was sufficiently accurate.

The d.c. consumption of the circuit described in the paper is approximately 45 milliamperes, and the duration of the discharge about 80 microseconds. The thyratron employed has a peak rating of 12·5 amperes, and two samples have each operated the circuit for about 1 300 hours without failure. In these circumstances it hardly seems worth while to adopt the cold-cathode tube, with its attendant ignition difficulties.

As a matter of interest the values of the components of my circuit for a standard frequency of 50 cycles per sec. are as follows:—

$R_1 =$ 4 000 ohms. $C_1 = 5\ \mu$F.
$R_2 =$ 10 000 ohms. $C_2 = 4\ \mu$F.
$R_3 =$ 100 000 ohms. $C_3 = C_4 = 2\ \mu$F.

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* Paper by Mr. R. S. J. Spilsbury (see vol. 79, p. 585).

MUTUAL IMPEDANCE OF CIRCUITS WITH RETURN IN A HORIZONTALLY STRATIFIED EARTH[*]

By W. G. RADLEY, Ph.D.(Eng.), Member, and H. J. JOSEPHS.

(*Paper received 3rd September, 1936.*)

SUMMARY

During recent years considerable attention has been given to investigation of the mutual impedance between two circuits with earth return. The problem is of importance. On a knowledge of this coupling depends the predetermination of the telephone interference which may arise from earth-fault currents or residual currents of harmonic frequency in power and traction systems. Theoretical formulae, which have been confirmed by field experiments, are available for its calculation where the earth can be considered to be homogeneous and of uniform conductivity. Experience has shown, however, that this condition is not always fulfilled. Where it is not, the assumption of an earth structure consisting of two horizontal layers of different conductivity would in nearly all cases give the accuracy required for engineering purposes. Curves have been prepared to facilitate calculation of the mutual impedance in the case of stratification of this type. They give an equivalent conductivity which, when introduced into the formulae relating to a homogeneous earth, will yield a mutual impedance equal in magnitude to that resulting from the given stratified conditions.

(1) MUTUAL IMPEDANCE WHERE THE EARTH IS HOMOGENEOUS

Where the earth is of uniform conductivity, the mutual impedance between two parallel earth-return circuits is derived from the Carson–Pollaczek formula, namely

$$M = -\frac{4j}{\gamma^2} + 4\frac{kei'\gamma - jker'\gamma}{\gamma} \quad . \quad . \quad . \quad (1)$$

where M is the generalized coefficient of mutual induction between the two circuits, $\gamma = x\sqrt{(4\pi\sigma\omega)}$, $\omega = 2\pi \times$ frequency of inducing current, x = separation between the two circuits, and σ = specific conductivity of the earth (c.g.s. units being used throughout).

Although described as a coefficient of mutual induction, M in effect takes account of the total coupling between the two circuits, resistive as well as reactive. If l is the length of the parallel, then $j\omega Ml$ gives the total mutual impedance between the circuits in magnitude and phase, apart from such additional coupling as may be due to end effects if both circuits are terminated near the same point.

Curves enabling the magnitude of the right-hand side of equation (1) to be read off directly for any value of γ likely to be encountered in calculations of telephone interference are available to communication and power engineers.[†]

Field experiments at Skillingaryd (Sweden) and Shap (England) with specially constructed inducing and induced lines confirmed the accuracy of equation (1) over a wide range of separation and frequency. In both these places the earth was of fairly uniform resistivity to a considerable depth. On the other hand, similar experiments at Munsingen and Oldenburg (Germany) had not given such agreement with theory, the measurements indicating that the apparent conductivity of the earth decreased with increasing frequency. As approximately the same variation was found in both places, the International Advisory Committee on Long-distance Telephony (C.C.I.F.[†]) directed in 1929 that, in the absence of other information, the conductivity should be taken as that given by the empirical formula

$$\sigma = \frac{1\cdot5 \times 10^{-12}}{\sqrt{f}} \text{ c.g.s. units} \quad . \quad . \quad . \quad (2)$$

where f is the frequency of the inducing current.

It has since been shown by one of the present authors[‡] that the variation of apparent conductivity with frequency which was observed can be completely explained if it is assumed that at each site a low-conductivity layer of earth is superimposed on one of higher conductivity.

Results sufficiently accurate for engineering purposes may frequently be obtained if the mutual impedance is calculated on the assumption of a uniform conductivity appropriate to the geological structure. On the other hand, localities are sometimes concerned where the conductivity is known to change with depth. It is then difficult to choose a value for use in equation (1). In most of these cases, however, the earth's crust could be represented approximately by a layer of uniform conductivity and definite depth superimposed on another of different conductivity and extending downwards indefinitely.

Riordan and Sunde,[§] and Josephs,[||] have independently published expressions for the mutual impedance between two wires on the surface of an earth divided by a horizontal plane of stratification into two layers of different conductivity. These expressions are not suitable for general use by engineers, a single calculation being a matter of several days' work. The engineering problem is greatly simplified by the curves given in this paper. These have been prepared in order that a ready means might be available of estimating inductive effects between power and communication lines having regard to a simple form of stratification of the earth. They give, in terms of the conductivities of the upper and lower layers, the

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[*] The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

[†] See, for example, Bibliography, (1).

[†] Comité Consultatif International des Communications Téléphoniques à Grande Distance.

[‡] See Bibliography, (2).

[§] *Ibid.*, (3).

[||] *Ibid.*, (4).

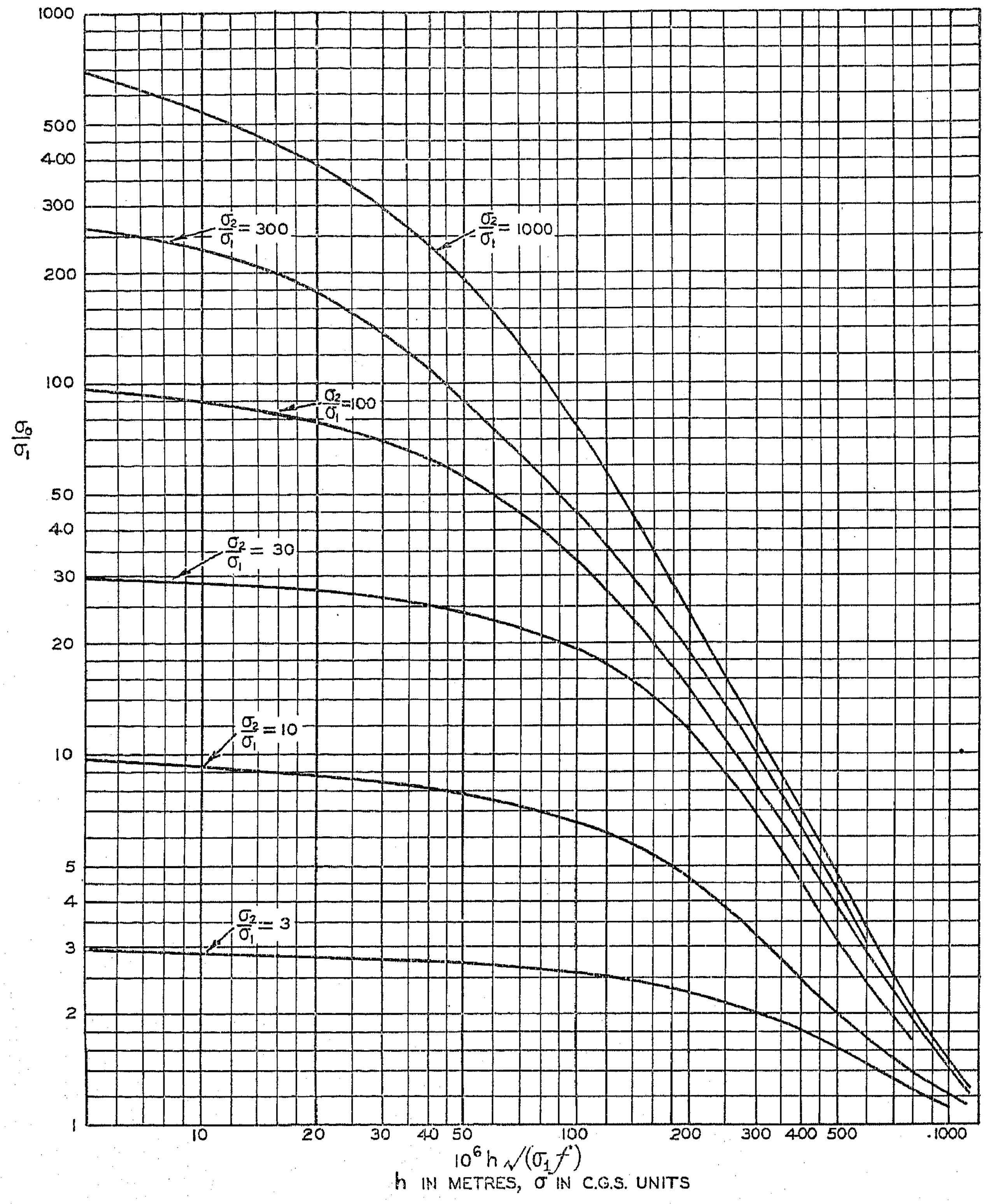

Fig. 1.—Equivalent conductivity for horizontally stratified earth, with $\sigma_2 > \sigma_1$.

depth of the plane of stratification and the frequency of the earth current, an equivalent conductivity which, when inserted in equation (1), enables the calculation to be made as if the earth were homogeneous.

(2) DERIVATION OF CURVES GIVING EQUIVALENT CONDUCTIVITY FOR TWO-LAYER STRATIFIED EARTH

With displacement currents neglected, the mutual impedance per unit length of parallel between two wires lying on the surface of the ground is given by

$$j\omega M = -4j\omega \int_0^{\infty} \frac{1}{g + \alpha\left(\dfrac{1+N}{1-N}\right)} \cos\left[gx\sqrt{(4\pi\sigma_1\omega)}\right]dg \quad (3)$$

it being assumed that the earth consists of a layer of uniform conductivity σ_1 and depth h, below which there is a region of uniform conductivity σ_2 extending to a very great depth. The meanings of the symbols in equation (3) are as follows:—

$$N = \left(\frac{\phi - \alpha}{\phi + \alpha}\right)e^{-2\alpha h\sqrt{(4\pi\sigma_1\omega)}},$$

$$\alpha = \sqrt{(g^2 + j)},$$

$$g = \text{variable of integration},$$

$$\phi = \sqrt{(g^2 + jK)},$$

and $K = \sigma_2/\sigma_1$.

The other quantities have the same significance as in equation (1).

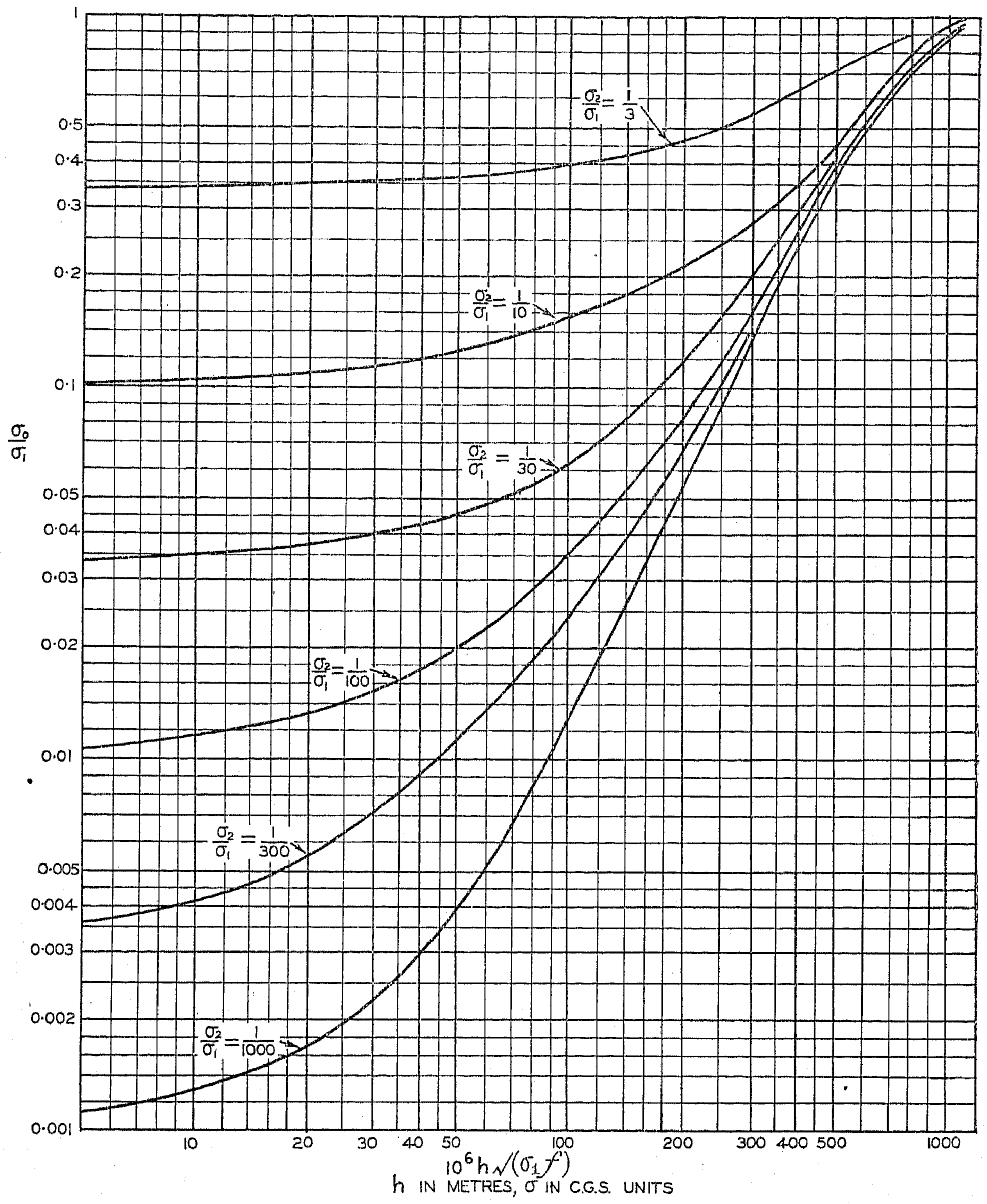

Fig. 2.—Equivalent conductivity for horizontally stratified earth, with $\sigma_2 < \sigma_1$.

By purely algebraic processes equation (3) may be transformed into:

$$j\omega M = -4\omega\int_0^\infty (\alpha - g)\cos\left[gx\sqrt{(4\pi\sigma_1\omega)}\right]dg$$

$$-4\omega\int_0^\infty \frac{(K-1)\left[1-j(\alpha-g)^2\right]e^{-\delta}\cos\left[gx\sqrt{(4\pi\sigma_1\omega)}\right]}{(\alpha+g)\left[(\alpha+\phi)^2+(K-1)(\alpha-g)^2e^{-\delta}\right]}dg \quad (4)$$

where $\delta = 2\alpha h\sqrt{(4\pi\sigma_1\omega)}$.

The first term on the right-hand side of equation (4) was independently evaluated by Pollaczek and by Carson, and gives equation (1) for the coefficient of mutual induction when the earth is of uniform conductivity σ_1 throughout. The second term gives the difference brought about by the change of conductivity from σ_1 to σ_2 at depth h below the surface. This term cannot readily be evaluated except by methods of graphical integration.

As the integrand in equation (4) contains no poles or essential singularities in the region between 0 and $\pi/4$, the variable g may be replaced by $s\sqrt{j}$. The complex numbers in the integrand are thereby reduced to real numbers. Thus when $2h \geqslant x$ the second term on the right-hand side of equation (4) reduces to

$$8\omega(K-1)\int_0^\infty \frac{\alpha_0(X\cos\theta\cosh\theta)}{W^2+X^2}ds$$

$$+\,8\omega(K-1)\int_0^\infty \frac{\alpha_0(W\sin\theta\sinh\theta)}{W^2+X^2}ds$$

$$+ 8j\omega(K - 1)\int_0^\infty \frac{\alpha_0(W \cos\theta \cosh\theta)}{W^2 + X^2}ds$$

$$- 8j\omega(K - 1)\int_0^\infty \frac{\alpha_0(X \sin\theta \sinh\theta)}{W^2 + X^2}ds$$

where

$$W = (K - 1) + \left[(\alpha_0 + \phi_0)\,(\alpha_0 + s)\right]^2 e^A \cos A,$$

$$X = \left[(\alpha_0 + \phi_0)\,(\alpha_0 + s)\right]^2 e^A \sin A,$$

$$\theta = \frac{1}{\sqrt{2}}\left[sx\sqrt{(4\pi\sigma_1\omega)}\right],$$

$$A = \sqrt{2}\left[h\sqrt{(4\pi\sigma_1\omega)}\right]\alpha_0,$$

$$\alpha_0 = \sqrt{(s^2 + 1)},$$

and $\phi_0 = \sqrt{(s^2 + K)}$.

The above expressions enable use to be made of tabulated values of functions, and thus reduce the labour of calculation enormously.

The present work has been undertaken in the following manner. With a fixed value of the parameter $x\sqrt{(4\pi\sigma_1\omega)}$, calculation of the coefficient of mutual induction was made over a wide range of variation of $h\sqrt{(4\pi\sigma_1\omega)}$ and for values of σ_2/σ_1 equal to 10, 100, 1 000, and 0·1, 0·01, and 0·001. Each coefficient of mutual induction so determined was then related to an equivalent earth conductivity σ_0 such that, when σ_0 was inserted into equation (1), the *magnitude* of the coefficient of mutual induction given by that equation was the same as that calculated for the stratified conditions. The results obtained are given in Figs. 1 and 2.

A few calculations were also made for values of σ_2/σ_1 equal to 3, 30, 300, and the reciprocals of these ratios. With their aid, corresponding curves have been interpolated in Figs. 1 and 2.

The curves for σ_2/σ_1 equal to 10, 100, 0·1, and 0·01, have been compared with those given by Card* for these values and have been found to be in fair agreement. As a further check on the work, the curves for the ratios 10 and 0·1 have been recalculated using the formulae published by Riordan and Sunde.

From investigation of the formulae it is found that when the other factors remain constant the ratio σ_0/σ_1 varies somewhat with the separation between the circuits. Equivalent conductivities calculated for extremely wide separations may differ by as much as 2·5 : 1 from those calculated for close separations, the conductivity of the lower layer having more effect on the result the greater the separation.

In practice, neither the conductivities of the layers nor the depth of the plane of stratification can be determined with precision, but the curves given are sufficiently accurate for engineering purposes over the whole range of separation and frequency likely to be encountered.

(3) PRACTICAL APPLICATION OF THE CURVES

As an illustration of the use of the curves in Figs. 1 and 2, suppose that calculation is required of the interference to be expected from a high-tension power line at a separation of 100 metres from an open-wire trunk telephone line. The ground over which the two lines run consists of a surface layer of clay 20 metres thick lying on the top of granite or other pre-Cambrian rocks. The clay has a resistivity of 1 000 ohm-cm, the rock of 300 000 ohm-cm. Noise in the telephone line is a product of the induced longitudinal voltage and the "coefficient of sensitivity" of the line. Taking 800 cycles per sec. as a typical frequency at which to calculate the longitudinal induction from harmonic currents, $10^6 h\sqrt{(\sigma_1 f)}$ equals 566 when h is in metres. From the appropriate curve in Fig. 2 the equivalent conductivity is equal to $0{\cdot}44\sigma_1$, i.e. $0{\cdot}44 \times 10^{-12}$ c.g.s. units. If pre-determination of the dangerous voltage at the fundamental frequency induced under earth-fault conditions is required, $10^6 h\sqrt{(\sigma_1 f)}$ equals 142 and the equivalent conductivity then becomes equal to $0{\cdot}04\sigma_1$, i.e. 4×10^{-14} c.g.s. units. Assume a separation of 100 metres between the lines. Using the curves previously published in the *Journal*,* to which reference was made in Section (1) of this paper, the mutual inductance is found to be 11·2 μH per km at a frequency of 800 cycles per sec. and 560 μH per km at 50 cycles per sec. If, on the other hand, the high-resistivity rock formation had extended to the surface the latter value would have become 800 μH per km, but the mutual inductance at the higher frequency would have been increased nearly 50 times—to 530 μH per km.

Table

Resistivity of upper layer	Conductivity of upper layer	Effective depth of flow, in metres	
		50 cycles per sec.	800 cycles per sec.
ohm-cm	c.g.s. units		
300	$3{\cdot}3 \times 10^{-12}$	60	15
1 000	10^{-12}	110	28
10 000	10^{-13}	360	90
100 000	10^{-14}	1 100	280
1 000 000	10^{-15}	3 600	900

The conductivity of the upper and lower layers and the depth of the plane of stratification can frequently be estimated approximately from the known geological structure. If not, they may be determined by measurements of the apparent resistivity, using the well-known 4-electrode method with varying spacing between the electrodes.

A point of practical importance is evident from the curves. It is that a negligible part of the earth current flows at a depth such that $10^6 h\sqrt{(\sigma_1 f)}$ is greater than 800. The Table gives in round figures the depth below which any change in conductivity of the earth has very little effect on the mutual impedance.

(4) CONCLUSIONS

Evaluation of the formulae for the mutual impedance between two circuits with earth return is extremely tedious when the earth is not of uniform conductivity. The curves given in this paper enable the magnitude of this impedance to be determined quickly on the assumption of a simple 2-layer stratification.

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* See Bibliography, (5).

* See Bibliography, (1).

Topographical irregularities invariably occur in practice and make any precise description of the earth's crust impossible. In view of this, the assumption on which the curves are based will give all the accuracy practicable for calculations of telephone interference. It may further be noted that the assumption of a single horizontal plane of stratification corresponds to the common arrangement of glacial drift or other overburden superimposed on older sedimentary or igneous rocks.

The curves have been calculated at the request of the International Advisory Committee on Long-Distance Telephony. They will be included in the next issue by this Committee of the *Directives* (guiding principles concerning measures to be taken in order to protect telephone lines against the disturbing influences of heavy-current or high-tension power lines).

Acknowledgment is made to the Engineer-in-Chief of the Post Office and to Captain B. S. Cohen, O.B.E., in charge of the Research Branch, for permission to publish this paper.

BIBLIOGRAPHY

(1) W. G. Radley and S. Whitehead: *Journal I.E.E.*, 1934, vol. 74, p. 238.

(2) S. Whitehead and W. G. Radley: *Proceedings of the Physical Society*, 1935, vol. 47, p. 606.

(3) J. Riordan and E. R. Sunde: *Bell System Technical Journal*, 1933, vol. 12, p. 162.

(4) H. J. Josephs: *Post Office Electrical Engineers' Journal*, 1934, vol. 27, p. 61.

(5) R. H. Card: *Transactions of the American I.E.E.*, 1935, vol. 54, p. 1153.

DISCUSSION ON "TRANSIT TIME EFFECTS IN DIODES, IN PICTORIAL FORM"*

Mr. E. B. Moullin (*communicated*): I think the authors have made a very useful contribution to our knowledge of transit time effects in diodes. Such analytical solutions as have been given previously are very involved, and it is almost impossible to disentangle the mechanism of the effect from the algebra which expresses its magnitude. The whole mechanism is clear in the authors' treatment.

I believe that some day the changes of inter-electrode capacitance discussed by the authors, and by others previously, will become an important factor in the frequency stability of short-wave generators. I have long been concerned with this problem, and experience shows that the fractional change of capacitance is a function of the anode current. The mechanism of this effect is not disclosed by the analysis of W. E. Benham or of Dr. F. B. Llewellyn; nor, I think, by the graphical treatment of the authors. In the hope of discovering in the analysis some place where this effect might belong, I attempted some two years ago to produce the classic analysis in a very simple manner which would show clearly where approximation, if any, exists. The process of my simple solution bears some resemblance to the method of the authors, and as it has not been published I hope it is appropriate to develop it briefly here.

My main interest was restricted to cases where $2\pi/\omega$ is much greater than T; where, say, the transit time is less than 1/20th of a period, which on small valves corresponds to frequencies less than about 40 megacycles per sec. Accordingly, it is a very close approximation to say that the current leaving the cathode increases uniformly with time during the whole flight of any single electron. Thus let the current leaving the cathode be

$$i = i_0(1 + bt) \quad . \quad . \quad . \quad . \quad . \quad (A)$$

where t is reckoned from the time of emission of some particular electron whose path is to be studied. In the authors' notation the greatest possible value of b would be $M\omega$, and this value of b would be relevant to an electron which was emitted when the current was I_m.†

The fundamental equation of motion for planar electrodes is

$$\frac{d^3x}{dt^3} = \frac{4\pi e}{m} i_0(1 + bt) = Ai_0(1 + bt)$$

Integrating this equation with the condition that $d^2x/dt^2 = dx/dt = 0$ when $t = 0$, it follows that

$$\frac{d^2x}{dt^2} = Ai_0t\left(1 + \frac{bt}{2}\right) \quad . \quad . \quad . \quad . \quad (B)$$

$$u \equiv \frac{dx}{dt} = \frac{Ai_0t^2}{2}\left(1 + \frac{bt}{3}\right) \quad . \quad . \quad . \quad . \quad (C)$$

and

$$x = \frac{Ai_0t^3}{6}\left(1 + \frac{bt}{4}\right) \quad . \quad . \quad . \quad . \quad (D)$$

The interpretation of equation (D) is that the distance travelled by an electron in time t is the same as would have been travelled if the current had been steady and of the value $i_0(1 + \frac{1}{4}bt)$. Or, in other words, at time

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* Paper by Drs. R. W. Sloane and E. G. James (see vol. 79, p. 291).

† For sinusoidal variations of i, equation (A) is equivalent to supposing that $M^2\omega^2T^2/6 << 1$: thus, using the authors' figure of $M = \frac{1}{2}$ and $\omega T = \pi/2$, we find that $M^2\omega^2T^2/6 = \frac{1}{10}$, and thus the approximation is justified

t after emission the electron will be in the position appropriate to a steady current equal in value to the current which was leaving the cathode at a time $\frac{3}{4}t$ previously. It is now necessary to express b in terms of x, by eliminating t from equations (C) and (D).

Thus

$$t^2 = \left(\frac{6x}{Ai_0}\right)^{\frac{2}{3}}\left(1 + \frac{bt}{4}\right)^{-\frac{2}{3}}$$

$$\therefore\ u = \frac{(6x)^{\frac{2}{3}}}{2}(Ai_0)^{\frac{1}{3}}\left(1 + \frac{bt}{3}\right)\left(1 + \frac{bt}{4}\right)^{-\frac{2}{3}}$$

$$= \frac{(6x)^{\frac{2}{3}}}{2}(Ai_0)^{\frac{1}{3}}\left(1 + \frac{bt}{6}\right),\ \text{since}\ \frac{bT}{4} << 1$$

$$= \frac{(6x)^{\frac{2}{3}}}{2}A^{\frac{1}{3}}\left[i_0\left(1 + \frac{bt}{2}\right)\right]^{\frac{1}{3}} \quad . \quad . \quad . \quad . \quad . \quad \text{(E)}$$

The interpretation of equation (E) is that at a distance x from the cathode an electron has the velocity corresponding to a steady current equal in value to that which was leaving the cathode at a time $t/2$ before the electron reached the point x in time t.

Since the space-charge density near any given electron is proportional to the current leaving the cathode when it was emitted, it follows from equation (D) that the space-charge density ρ at distance x from the cathode is that appropriate to a steady current $i_0\ (1 + \frac{1}{4}bt)$.

We may now use the well-known equations for space-charge and velocity, applicable to a space-charge-limited planar diode in the steady state, and hence obtain

$$\rho u \equiv i = i_0\left(1 + \frac{bt}{4}\right)^{\frac{2}{3}}\left(1 + \frac{bt}{2}\right)^{\frac{1}{3}} \simeq i_0\left(1 + \frac{bt}{3}\right) \quad . \quad \text{(F)}$$

thus showing that the conduction current caused by electrons at distance x from the cathode is that appropriate to a steady current equal to that leaving the cathode at a time $\frac{2}{3}t$ earlier. Hence it follows that

$$\frac{1}{4\pi}\frac{\partial\epsilon}{\partial t} = \frac{2}{3}bti_0 \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(G)}$$

We will now make the simplification that $t = (x/d)^{\frac{1}{3}}T$, where T is the transit time corresponding to current I_m and d is the distance between anode and cathode. We wish to express the current as a continuous function of time, and hence from (F) write

$$i = I_m\left[1 + M\sin\omega\left(t - \frac{2\theta}{3}\right)\right]$$

where $\theta = (x/d)^{\frac{1}{3}}T$, and t now refers to time in the cycle and not to time from emission of a particular electron.

Therefore

$$i \simeq I_m\left\{1 + M\left[\sin\omega t - \frac{2}{3}\left(\frac{x}{d}\right)^{\frac{1}{3}}\omega T\cos\omega t\right]\right\}$$

$$= I_m\left\{1 + M\left[\sin\omega t - \tfrac{2}{3}\,\omega T\cos\omega t\right]\right\},\ \text{if}\ x = d \quad \text{(H)}$$

Since the total anode current is $i = I_m(1 + M\sin\omega t)$, it follows that the displacement current at the anode is $\frac{2}{3}MI_m\omega T\cos\omega t$, which is in conformity with (G).

The potential may be calculated by the help of equation (B), which gives

$$\epsilon = 4\pi i_0 t\left(1 + \frac{bt}{2}\right) \simeq 4\pi\left(\frac{6x}{A}\right)^{\frac{1}{3}}\left[i_0\left(1 + \frac{5}{8}bt\right)^{\frac{2}{3}}\right],\ \text{from (D)}$$

$$= 4\pi\left(\frac{6x}{A}\right)^{\frac{1}{3}}I_m^{\frac{2}{3}}\left[1 + M\sin\omega\left(t - \frac{3}{8}\theta\right)\right]^{\frac{2}{3}}$$

where $\theta \simeq \left(\frac{x}{d}\right)^{\frac{1}{3}}T$. Thus

$$\epsilon \simeq 4\pi\left(\frac{6x}{A}\right)^{\frac{1}{3}}I_m^{\frac{2}{3}}\left[\left(1 + \frac{2}{3}M\sin\omega t\right) - \frac{M}{4}\left(\frac{x}{d}\right)^{\frac{1}{3}}\omega T\cos\omega t\right],\ \text{if}\ M << 1$$

$$\therefore\ V = \int_0^d \epsilon dx = 4\pi\left(\frac{6}{A}\right)^{\frac{1}{3}}I_m^{\frac{2}{3}}\left[\frac{3}{4}\left(1 + \frac{2}{3}M\sin\omega t\right)d^{\frac{4}{3}} - \frac{3}{20}M\omega Td^{\frac{4}{3}}\cos\omega t\right]$$

$$= V_m\left[1 + \frac{2}{3}M\left(\sin\omega t - \frac{3}{10}\omega T\cos\omega t\right)\right] \quad . \quad \text{(I)}$$

Hence the alternating component of total anode current leads the alternating component of anode potential by an angle ϕ, such that $\phi = \frac{3}{10}\omega T$.

If the diode is regarded as equivalent to a small capacitance K in parallel with a resistance R, then it follows that

$$KR = \frac{3}{10}T$$

$$\therefore\ K = \frac{9}{20}\frac{I_mT}{V_m}$$

It can readily be shown* that

$$T = \frac{\text{Charge on anode}}{I_m}$$

$$= \frac{\frac{4}{3}CV_m}{I_m}$$

$$\therefore\ \frac{K}{C} = \frac{3}{5}$$

This is the ratio found in the paper, and deduced first by Benham.

It follows from equations (G) and (H) that the alternating component of conduction current at the anode is out of phase with the potential by an angle ϕ', such that

$$\phi' = \frac{2}{3}\omega T - \frac{3}{10}\omega T$$

$$= \frac{11}{30}\omega T$$

Hence if the conductive path be represented by a small inductance L in series with a resistance R, it follows that

$$L = \frac{11}{30}RT = \frac{22}{90}\frac{V_mT}{I_m} = \frac{11}{15}\pi dT^2$$

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* See, for example, E. B. MOULLIN: *Wireless Engineer*, 1935, vol. 12, p. 371.

The expression for $\partial V/\partial x = \epsilon$ appears in the set of equations culminating in (h). If $\partial\epsilon/\partial t$ is found from this, it follows that the displacement current at the anode is $\frac{2}{3}MI_m\omega T(\cos\omega t + \frac{3}{8}\omega T\sin\omega t)$, which thus is not precisely in phase quadrature with the voltage. It differs from phase quadrature by an angle ϕ'' such that

$$\phi'' = \left(\frac{3}{8} - \frac{3}{10}\right)\omega T = \frac{3}{40}\omega T$$

It follows from this that the capacitance $\frac{4}{3}C$ must be represented as being in series with a resistance r such that $r = (9/80)R$. Thus we have arrived at the equivalent circuit depicted by Llewellyn[*] and whose parameters have the values tabulated by him (*loc. cit.*). Or, alternatively, we have found the same phase angles for ρ, V, etc., as were found and tabulated by Benham.[†]

In arriving at equation (H) an approximation has been made which is equivalent to assuming that all electrons pass across in the same transit time T_m, which is the time appropriate to the current I_m: this approximation is not necessary. Returning to equation (D), we have

$$d = \frac{AT^3}{6}I_m\left[1 + M\sin\omega\left(t - \frac{3}{4}T\right)\right]$$
$$\equiv \frac{AT^3}{6}I_m[1 + M\sin y]$$

where T is now a transit time which varies according to the epoch in the cycle at which the electron was emitted. On expanding the term in brackets by the binomial theorem and converting $\sin^n y$, etc., into $\sin ny$, etc., it follows that

$$T = T_m(\alpha - \beta\sin y - \gamma\cos 2y + \delta\sin 3y\ \ldots)$$

where $$\alpha = 1 + \frac{M^2}{9}\left(1 + \frac{35}{72}M^2 + \frac{455}{1458}M^4\ldots\right)$$
$$\beta = \frac{M}{3}\left(1 + \frac{7}{18}M^2 + \frac{455}{1794}M^4 + \ldots\right)$$
$$\gamma = \frac{M^2}{9}\left(1 + \frac{35}{54}M^2 + \frac{455}{972}M^4 + \ldots\right)$$
$$\delta = \frac{7}{162}M^3\left(1 + \frac{65}{72}M^2 + \ldots\right)$$

$$\therefore\ T \simeq T_m(\alpha - \beta\sin\omega t + \tfrac{3}{4}\beta\omega T\cos\omega t - \gamma\cos 2\omega t + \tfrac{3}{2}\gamma\omega T\sin 2\omega t + \ldots)$$
$$\therefore\ T \simeq T_m(\alpha - \beta\sin\omega t + \tfrac{3}{4}\beta\omega T_m\cos\omega t - \gamma\cos 2\omega t + \tfrac{3}{2}\gamma\omega T_m\sin 2\omega t + \ldots)$$
$$\simeq T_m(\alpha - \beta\sin\omega t - \gamma\cos 2\omega t + \delta\sin 3\omega t + \ldots) \quad \text{(J)}$$

Substituting this value of T in equation (H), we have

$$i = I_m[1 + M\sin\omega t - \tfrac{2}{3}M\omega T_m(\alpha - \beta\sin\omega t - \gamma\cos 2\omega t\ \ldots)\cos\omega t]$$
$$= I_m\left[1 + M\sin\omega t - \frac{2}{3}M\omega T_m\left(\alpha - \frac{\gamma}{2}\right)\cos\omega t + \frac{M\omega T_m}{3}(\beta - \delta)\sin 2\,\omega t\ldots\right] \quad . \quad \text{(K)}$$

This differs from equation (H) only in the production of higher harmonic terms and in replacing T_m by $T_m(\alpha - \frac{1}{2}\gamma)$.

Now $$\left(\alpha - \frac{\gamma}{2}\right) = 1 + \frac{M^2}{18}\left(1 + \frac{35}{108}M^2 + \ldots\right)$$
$$= 1{\cdot}055,\ \text{if}\ M = \tfrac{1}{2}$$
$$= 1{\cdot}1,\ \text{if}\ M = 1.$$

Thus it appears that equation (H) is very closely correct for all values of M, provided only that $M^2\omega^2T_m{}^2/6 << 1$.

Using the same process on equations (B) and (D), it follows that

$$\epsilon = 4\pi\left(\frac{6x}{A}\right)^{\frac{1}{3}}I_m^{\frac{2}{3}}\left[\left(1 - \frac{M^2}{18} - \frac{7}{648}M^4\right) + \frac{2}{3}M\left(1 + \frac{M^2}{18}\right)\sin\omega\left(t - \frac{3}{8}\theta\right) + \frac{M^2}{18}\left(1 + \frac{7M^2}{27}\right)\cos 2\omega\left(t - \frac{3}{8}\theta\right) + \ldots\right]$$
$$= 4\pi\left(\frac{6x}{A}\right)^{\frac{1}{3}}I_m^{\frac{2}{3}}\left[\left(1 - \frac{M^2}{18} - \frac{7}{648}M^4\right) + \frac{2}{3}M\left(1 + \frac{M^2}{18}\right)\sin\omega t + \frac{M^2}{18}\left(1 + \frac{7M^2}{27}\right)\cos 2\omega t - \frac{M}{4}\left(1 + \frac{M^2}{18}\right)\omega\theta\cos\omega t + \frac{M^2}{24}\left(1 + \frac{7M^2}{27}\right)\omega\theta\sin 2\omega t + \ldots\right]$$

where now

$$\theta = \left(\frac{x}{d}\right)^{\frac{1}{3}}T$$

T being given by equation (J).

Then it follows, after much reduction, that

$$V = V_m\left(1 - \frac{M^2}{18}\right)\left\{1 + \frac{2}{3}M\left(1 + \frac{M^2}{9}\right)\left[\sin\omega t - \frac{3}{10}\omega T_m\left(1 + \frac{M^2}{12}\right)\cos\omega t\right] + \frac{M^2}{18}\left(1 + \frac{17}{54}M^2\right)\left[\cos 2\omega t + \frac{6}{5}\omega T_m\left(1 + \frac{M^2}{54}\right)\sin 2\omega t\right] + \ldots\right\} \quad . \quad . \quad . \quad . \quad \text{(L)}$$
$$= 0{\cdot}986V_m[1 + 0{\cdot}38\sin(\omega t - 25^\circ\,45') + 0{\cdot}0174\sin(2\omega t + 27^\circ\,42')]$$

if $M = \frac{1}{2}$ and $\omega T_m = \frac{1}{2}\pi$.

The corresponding expression derived by the graphical process is

$$V = 0{\cdot}986V_m[1 + 0{\cdot}32\sin(\omega t - 25^\circ\,47') + 0{\cdot}0108\sin(2\omega t + 60^\circ\,5')]$$

It is interesting to notice that equation (L) shows that the phase angle of the fundamental component is proportional to $(1 + \frac{1}{12}M^2)$: consequently it is sensibly independent of M. No doubt the problem of the saturated diode could be dealt with in a similar way, but lack of space precludes this being done here.

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[*] *Proceedings of the Institute of Radio Engineers*, 1933, vol. 21, p. 1549, Fig. 8.

[†] *Philosophical Magazine*, 1931, vol. 11, p. 467, Table 2, col. 1.

For cylindrical electrodes, the equation of motion is

$$\frac{d^3r}{dt^3} + \left(\frac{dr}{dt} \times \frac{d^2r}{dt^2}\right) = \frac{4\pi e}{m} i_0$$

I think an approximate solution of this can be obtained by a similar method of approach. Such attempts as I made suggested that the phase angle between total current and voltage is greater with cylindrical electrodes than it is with planar electrodes. This does seem probable because it is well known that the transit time with cylindrical electrodes is about half that for planar electrodes with the same spacing and voltage.

It is important that this phase angle should be measured, but the experimental difficulties are great. If the phase angle ϕ is that appropriate to the geometrical capacitance, then for planar electrodes it can be shown that

$$\phi = \frac{\pi f}{T_0}$$

and hence it follows that ϕ is of the order of 1° of arc if f is 10^6 cycles per sec.

Drs. R. W. Sloane and E. G. James (*in reply*): We have to thank Mr. Moullin for a very considerable simplification of the analysis of transit-time problems. The general analysis, best given by Dr. Llewellyn,[*] provides a formally complete method of proceeding to any degree of approximation to the solution. It gives approximate results in the form of formulae which may be widely applied,[*] but the labour of calculation increases very rapidly as the degree of accuracy is increased by successive orders.

In Mr. Moullin's form of the analysis, a definite approximation is made in the original equation and no successively closer approximations are possible. The advantage gained is that the relationship between x and t, Mr. Moullin's equation (D), becomes algebraic and the equations are then soluble by an easily understood form of approximation.

The graphical method, given in the paper, is most useful for explanatory purposes, as the argument is nowhere obscured by analysis. The method is laborious but is entirely free from formal approximations, and the limits of accuracy are purely arithmetical and graphical.

It will be seen that the problem in every case (with plane parallel electrodes) is to find the solution to equation (9) of the paper from equation (5) and three boundary conditions. The equations and processes of solution are not open to serious doubt, and discrepancies between theory and practice, such as the capacitance effect mentioned by Mr. Moullin, are no doubt due not to analytical approximations but to the use of idealized boundary conditions such as zero field and velocity at the cathode.

[*] *Bell System Technical Journal*, 1935, vol. 14, p. 632

[*] F. B. LLEWELLYN: "Equivalent Networks of Negative-Grid Vacuum Tube at Ultra-High Frequencies," *ibid.*, 1936, vol. 15, p. 575.

PROCEEDINGS OF THE INSTITUTION

902ND ORDINARY MEETING, 22ND OCTOBER, 1936

Mr. J. M. Kennedy, O.B.E., the retiring President, took the chair at 6 p.m.

The minutes of the Annual General Meeting held on the 7th May, 1936, and of the Ordinary Meeting held on the same day, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

The Chairman announced that, during the period May to September, 699 donations and subscriptions to the Benevolent Fund had been received, amounting to £647. A vote of thanks was accorded to the donors.

The Premiums (see vol. 78, page 726, and vol. 79, page 239) awarded for papers read or published during the past session were presented by the Chairman to such of the recipients as were able to be present.

Mr. Kennedy then vacated the chair, which was taken by the new President, **Mr. H. T. Young,** amid applause.

Mr. W. B. Woodhouse: Another session is about to begin and to-day Mr. Kennedy retires to the obscurity in which Past-Presidents are reputed to dwell. He will, I believe, find that his experience as President of The Institution, and his enlarged acquaintance with the members, will stand him in good stead in his future activities, and I am sure that he will carry with him the good wishes of all the members. His has been a crowded year of office and, even to one of his enthusiastic and zealous nature, has, I trust, not proved unsatisfactory. It has been a year of great national trade recovery, encouraged and assisted by the electrical activities in which our members are engaged. Electrical communications, transport, power, and light, have all made notable progress in the past year. Our much advertised telephone system has 1 million London subscribers. Our much-criticized electricity-supply system has over 7 times that number, and the sales of electricity are increasing so rapidly that the progress which Mr. Kennedy set in his Presidential Address as a goal to be aimed at will, I think, be attained before the time limit which he set expires. Here may I recall that it is 46 years since his distinguished father, the late Sir Alexander Kennedy, turned his thoughts to the development of electricity supply—an object which our retiring President has continued to pursue with such ability. Their joint contribution to the progress of that industry, apart from their other engineering activities, must indeed be a proud family record. It has been a year of great progress in The Institution. The membership has grown apace, the activities of The Institution have been extended in all directions, and one may note with appreciation the continued tendency on the part of public bodies and public authorities, both at home and abroad, to seek advice and assistance in electrical matters from The Institution. All these movements have been encouraged by the distinction, the energy, and the ability of our retiring President, and you will not wish him to depart from the chair without an expression of your hearty appreciation of the good work which he has done for the industry, for those engaged in it, and for The Institution itself. The formal resolution which I have to move is this: " That the best thanks of The Institution be accorded to Mr. J. M. Kennedy for the very able manner in which he has filled the office of President during the past year."

Mr. W. E. Highfield: I most warmly support the vote of thanks to Mr. Kennedy, moved in such graceful words by Mr. Woodhouse. Those who have worked with Mr. Kennedy know the extraordinary zeal with which he has attended to the business of The Institution. No work was too much for him to do: no town was too far distant for him to travel to, so that every district, every sub-district, every committee, and every sub-committee, has enjoyed the personal touch of the President. In that respect he has set up a record which I think will stand for all time.

The resolution was then carried with acclamation.

Mr. J. M. Kennedy: I would indeed be unfeeling if I were not extremely gratified at the very kind things which Mr. Woodhouse and Mr. Highfield have said about me. I entered upon my term of office a year ago with considerable misgiving, and if I have been of any assistance to The Institution, The Institution has been of great assistance to me. I can assure you that the President learns a good deal in his term of office, so much so that at the present time I feel how much better I could do the job if I had to do it over again. I should like to say that whatever value my services may have been to The Institution has only been made possible by the co-operation of my colleagues, and I therefore desire to express my most hearty thanks first of all to the Vice-Presidents, to the whole of the Council, and to the Chairmen of the various Committees. Last, but not least, my thanks are due to the whole of the staff of The Institution for the very courteous way in which they have always received me and helped me in my various difficulties throughout my term of office.

The President then delivered his Inaugural Address (see page 1).

Sir Thomas Purves: My duty is to propose the following resolution: " That the best thanks of The Institution be accorded to Mr. H. T. Young for his interesting and instructive Presidential Address and that, with his permission, the Address be printed in the *Journal* of The Institution." Mr. Young's Address has obviously been animated by a definite purpose and one that appeals to all of us. It has been illustrated by a great many interesting facts and figures; among which it is good to see the number of fatalities due to electrical causes set out in proper perspective. Mr. Young has made a good start, and I feel sure that he will follow through to the satisfaction of all of us. I think he will find the office of President of this Institution both congenial and happy, and one that will lead to many new friendships and to experiences upon which he will always be pleased to look back. I am sure I speak for you all when I tell Mr. Young that we very much appreciate the good services he has already rendered to The Institution, that we wish him well, and that our active sympathy and support during his year of office as our President will always be his to command.

Mr. Johnstone Wright: It gives me great pleasure to second the vote of thanks to Mr. Young for his very informative and inspiring Address. I heartily endorse all that Sir Thomas has said about Mr. Young and his Address. I always feel that the Presidential Address is much in keeping with the King's Speech: while it does not act as a guide to the session's work it does indicate as a rule things to come. Mr. Young has not disappointed us in that, and I am sure we all hope that some of the things which he has envisaged will take shape during his year of office.

The vote of thanks was carried with acclamation and, after the President had briefly replied, the meeting terminated.

INSTITUTION NOTES

PATRON OF THE INSTITUTION

The President of The Institution has received the following Memorandum from the Keeper of the Privy Purse:—

Privy Purse Office,
Buckingham Palace, S.W.

MEMORANDUM.

The Keeper of the Privy Purse is commanded by The King to state that His Majesty is pleased to intimate to those Societies and Institutions which were recently granted Patronage by King Edward VIII, that they may continue to show the Sovereign as their Patron during the present Reign, unless otherwise notified.

14th December, 1936.

OVERSEAS MEMBERS AND THE INSTITUTION

During the period 1st September to 31st December, 1936, the following members from overseas called at The Institution and signed the "Attendance Register of Overseas Members":—

Anand, L. S. (*Lahore*).
Atkins, J. W. (*Calcutta*).
Bearman, C. W. G. (*Wellington, N.Z.*).
Beattie, A. R. (*Calcutta*).
Beckett, T. R., B.Sc.(Eng.) (*Lagos, Nigeria*).
Beveridge, N. G. (*Vereeniging*).
Brazel, Major C. H., M.C. (*Colombo*).
Butcher, J. D. (*Hong Kong*).
Dibben, E., B.Sc.(*Bombay*).
Ewing, S. E. T. (*Johannesburg*).
Gray, R. A. G. (*Montreal*).
Hardman, J. (*Johore*).
Hayward, G. B., B.A. (*Barcelona*).
Hill, D. S. (*Hong Kong*).
Jacob, H. F. D. (*Los Angeles*).
Jehu, J. W., B.Sc.Tech. (*Lagos, Nigeria*).
McNaughton, Major-General A. G. L., C.B., C.M.G., D.S.O. (*Ontario*).
Mohan, A. S. (*Rawalpindi*).
Neill, D. T. (*San Rafael, Argentina*).
Ogden, Captain G. W., B.A. (*Khartoum*).
Onder, A. K. (*Istanbul*).
Patel, N. K. (*Bombay*).
Skinner, L. D. (*Hong Kong*).
Smith, A. J. (*Lower Hutt, N.Z.*).
Veith, F. S. (*Zurich*).
Wallace, M. H. (*Bombay*).
Websdale, Major G. J., M.C. (*Almeria*).
Whyte, W. L. (*Ceará, Brazil*).

LOCAL CENTRE COMMITTEES ABROAD

The present constitution of the Local Centre Committees abroad is as follows:—

Argentine

R. Wright (*Chairman*).
R. G. Parrott (*Vice-Chairman and Hon. Secretary*).

K. N. Eckhard.
F. Harris.
H. J. McPhail.
G. W. Munday.
H. C. Siddeley.
L. P. Thomson.
W. S. Wheeler.

China

C. R. Webb (*Chairman*).
J. Haynes Wilson, M.C. (*Vice-Chairman and Hon. Secretary*).

S. Y. Chang.
N. Denison.
S. Flemons.
W. C. Gomersall.
A. H. Gordon.
A. H. Harvey.
J. A. McKinney.
A. J. Percival.
C. M. Perrin.
J. S. Whitney.

LOCAL COMMITTEES ABROAD

The present constitution of the Local Committees abroad is as follows:—

Australia

NEW SOUTH WALES.

V. L. Molloy (*Chairman*).

V. J. F. Brain, B.E.
L. F. Burgess, M.C.
W. R. Caithness.
E. F. Campbell, B.Eng.
R. V. Hall, B.E.
A. S. Plowman.
P. S. Saunderson.

W. J. McCallion, M.C. (*Hon. Secretary*).

QUEENSLAND.

J. S. Just (*Chairman and Hon. Secretary*).

W. Arundell.
A. Boyd, D.Sc.
W. M. L'Estrange.
F. Walker.

SOUTH AUSTRALIA.

F. W. H. Wheadon (*Chairman and Hon. Secretary*).

E. V. Clark.
J. S. Fitzmaurice.
Sir W. G. T. Goodman.
W. Inglis.
P. Kennedy.
D. E. McLaren.

VICTORIA AND TASMANIA.

H. R. Harper (*Chairman and Hon. Secretary*).

F. W. Clements.
J. M. Crawford.
H. C. Newton.
T. P. Strickland.
R. J. Strike.

WESTERN AUSTRALIA.

J. R. W. Gardam (*Chairman*).

F. C. Edmondson.
Prof. P. H. Fraenkel, B.E.
S. Johnson.
W. H. Taylor.

A. E. Lambert, B.E. (*Hon. Secretary*).

Ceylon

Major C. H. Brazel, M.C. (*Chairman*).

D. P. Bennett.
C. H. Jones.
A. T. Kingston.
D. Lusk.
G. E. Misso.
D. K. Mukherji.
J. Shillitoe.
E. Skinner.

G. L. Kirk (*Hon. Secretary*).

India

Bombay.

R. G. Higham (*Chairman*).

S. J. W. Baldwin.
C. M. Cock.
K. M. Dordi.
N. R. Khambati.
E. G. Lazarus.
S. E. Povey.

A. L. Guilford, B.Sc.Tech. (*Hon. Secretary*).

Calcutta.

F. T. Homan (*Chairman*).

H. J. Allinson.
N. C. Bhattacharji.
C. R. Bland.
C. C. T. Eastgate.
P. S. E. Jackson.
S. W. Redclift.
Prof. F. W. Sharpley, F.R.S.E.

D. H. P. Henderson (*Hon. Secretary*).

Lahore.

Prof. T. H. Matthewman (*Chairman*).

A. T. Arnall.
H. J. Darling.
B. Paul.
M. O. Sidiqui.

J. C. Brown, B.Sc. (*Hon. Secretary*).

Madras.

E. J. B. Greenwood (*Chairman and Hon. Secretary*).

L. Henshaw.
R. M. Steele.

New Zealand

F. T. M. Kissel, B.Sc. (*Chairman*).

R. H. Bartley.
M. C. Henderson.
E. Hitchcock.

J. McDermott (*Hon. Secretary*).

South Africa

Transvaal.

W. Elsdon Dew (*Chairman and Hon. Secretary*).

J. B. Bullock.
S. E. T. Ewing.
V. Pickles.
B. Price.
Prof. O. R. Randall, Ph.D., M.Sc.
A. Rodwell.
L. B. Woodworth.

COMMITTEES, 1936-1937

Meter and Instrument Section Committee

Chairman: G. F. Shotter.
Vice-Chairman: H. C. Turner.
Immediate Past-Chairman: O. Howarth.

H. M. Barlow, Ph.D.
L. C. Benton.
J. W. Carter.
B. S. Cohen, O.B.E.
S. James.
F. C. Knowles.
C. G. Mayo, M.A., B.Sc.
H. S. Petch, B.Sc.(Eng.).
W. Phillips.
A. J. Pitt.
R. S. J. Spilsbury.
J. G. Wellings.

And

A representative of the Council.
The Chairman of the Papers Committee.

Transmission Section Committee

Chairman: Dr. P. Dunsheath, O.B.E., M.A.
Vice-Chairman: J. L. Eve.
Immediate Past-Chairman: W. Fennell.

H. J. Allcock, M.Sc.
W. C. Bexon.
J. H. C. Brooking.
H. W. Grimmitt.
P. V. Hunter, C.B.E.
F. W. Main.
Major W. N. M. Morecombe, O.B.E., B.Sc.(Eng.), R.E. (Ret.).
F. W. Purse.
P. E. Rycroft, M.B.E.
S. R. Siviour.
R. J. J. Swan.
Johnstone Wright.

And

A representative of the Council.
The Chairman of the Papers Committee.
The following representatives of Government Departments:—
Central Electricity Board: C. W. Marshall, B.Sc.
Electricity Commission: C. G. Morley New.
Post Office: Col. H. Carter, B.Sc.

Wireless Section Committee

Chairman: E. Mallett, D.Sc.(Eng.).
Vice-Chairman: E. B. Moullin, M.A.
Immediate Past-Chairman: R. A. Watson Watt, B.Sc.(Eng.).

H. Bishop, B.Sc.(Eng.).
W. J. Brown, B.Sc.
S. Brydon, D.Sc.
W. T. Ditcham.
N. F. S. Hecht.
J. Joseph.
A.H.Mumford,B.Sc.(Eng.).
Frederick Smith.
S. B. Smith.
R. L. Smith-Rose, Ph.D., D.Sc.
C. E. Strong, B.A.I.
W. Ure, B.Sc.

And

A representative of the Council.
The Chairman of the Papers Committee.
The following representatives of Government Departments:—
Admiralty: Capt. W. T. Makeig-Jones, R.N.
Air Ministry: F. S. Barton, M.A., B.Sc.
Post Office: A. J. Gill, B.Sc.(Eng.).
War Office: Col. J. P. G. Worlledge, O.B.E.

Among the Committees appointed* by the Council for 1936–1937 are the following:—

Benevolent Fund Committee

The President (*Chairman*).

A. H. M. Arnold, D.Eng.	representing the Council.
J. R. Beard, M.Sc.	
F. W. Crawter	
P. Good	
P. J. Robinson, M.Eng.	
J. W. Thomas, LL.B., B.Sc.Tech.	
A. L. Lunn	representing the Contributors.
J. F. Shipley	
W. C. P. Tapper	

And the Chairman of each Local Centre in Great Britain and Ireland.

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* The President is, *ex-officio*, a member of all Committees of The Institution.

Informal Meetings Committee

F. Jervis Smith (*Chairman*).

S. C. Bartholomew, M.B.E.
H. Brierley.
A. F. Harmer.
Forbes Jackson.
L. M. Jockel.
A. F. W. Richards.
J. F. Shipley.
P. P. Wheelwright.
M. Whitgift.

And

A representative of the General Purposes Committee.
The Chairman of the Papers Committee.
The Chairman of the London Students' Section.

Joint Committee for National Certificates and Diplomas in Electrical Engineering (England and Wales)

E. S. Byng W. E. Highfield Prof. E. W. Marchant, D.Sc.	representing the I.E.E.
F. T. Chapman, D.Sc. A. Morley, D.Sc. H. J. Shelley, B.Sc.	representing the Board of Education.

Joint Committee for National Certificates and Diplomas in Electrical Engineering (Scotland)

Prof. G. W. O. Howe, D.Sc. D. S. Munro R. Robertson, B.Sc. Prof. S. Parker Smith, D.Sc.	representing the I.E.E.
Dr. J. S. W. Boyle J. G. Frewin W. Hyslop F. W. Michie	representing the Scottish Education Department.

Local Centres Committee

J. R. Beard, M.Sc.
T. Carter.
A. P. M. Fleming, C.B.E., M.Sc.
F. E. J. Ockenden.
Col. Sir Thomas F. Purves, O.B.E.
J. W. Thomas, LL.B., B.Sc.Tech.
W. B. Woodhouse.

And the Chairman of each Local Centre and Sub-Centre

Overseas Activities Committee

Sir Noel Ashbridge, B.Sc.(Eng.).
Lieut.-Col. K. Edgcumbe, T.D.
W. G. Hendrey.
J. S. Highfield.
C. le Maistre, C.B.E.
C. C. Paterson, O.B.E.

And

The Chairman of the Finance Committee.
The Chairman of the General Purposes Committee.
The Chairman of the Membership Committee.
The Chairman of the Papers Committee.

Also the following co-opted members:—

Prof. J. K. Catterson-Smith, M.Eng.
W. P. Gauvain.
F. Gill, O.B.E.
A. S. Herbert.
A. C. Kelly.
F. Lydall.
J. T. Mertens.
E. A. Mills.
H. Nimmo.
E. E. Sharp.
A. L. Stanton.
C. S. Taylor.
V. Watlington, M.B.E.

Scholarships Committee

Prof. J. K. Catterson-Smith, M.Eng.
J. M. Donaldson, M.C.
Prof. J. T. MacGregor-Morris.
Prof. E. W. Marchant, D.Sc.
H. Marryat.
R. W. Paul.
P. J. Robinson, M.Eng.
Johnstone Wright.

"Science Abstracts" Committee

L. G. Brazier, Ph.D., B.Sc.
T. Carter.
Prof. J. T. MacGregor-Morris.
C. C. Paterson, O.B.E.

And	*Representing*
J. H. Awbery, B.A., B.Sc. A. Ferguson, M.A., D.Sc. D. Owen, B.A., D.Sc. Prof. G. F. J. Temple, D.Sc., Ph.D.	Physical Society.
Prof. G. P. Thomson, M.A., F.R.S.	Royal Society.

Ship Electrical Equipment Committee

A. G. S. Barnard.
Major B. Binyon, O.B.E., M.A.
J. H. Collie.
Dr. P. Dunsheath, O.B.E., M.A.
S. Harcombe, M.A., B.Sc.
A. Henderson.
J. F. W. Hooper.
P. V. Hunter, C.B.E.
J. W. Kempster.
A. Cecil Livesey.
W. McClelland, C.B., O.B.E.
S. W. Melsom.
N. W. Prangnell.
Col. A. P. Pyne.
T. A. Sedgwick.
H. D. Wight.
Ernest T. Williams, O.B.E.

And	*Representing*
H. Cranwell W. T. Williams, O.B.E.	Board of Trade.
B. Hodgson T. R. Thomas	British Corporation Register of Shipping and Aircraft.
T. Ratcliffe, M.Sc.Tech. C. W. Saunders	British Electrical and Allied Manufacturers' Association.
W. Cross	Electrical Contractors' Association.
S. B. Jackson A. E. Laslett	The Institute of Marine Engineers.
J. F. Nielson	Institution of Engineers and Shipbuilders in Scotland.
W. J. Belsey	Institution of Naval Architects.
S. F. Dorey, D.Sc. G. O. Watson	Lloyd's Register of Shipping.
W. S. Wilson	North-East Coast Institution of Engineers and Shipbuilders.
(To be nominated)	Electrical Contractors 'Association of Scotland.

Wiring Regulations Committee

Ll. B. Atkinson.
H. J. Cash.
J. R. Cowie.
P. Dunsheath, O.B.E., M.A.
P. Good.
R. Grierson.
J. F. W. Hooper.
P. V. Hunter, C.B.E.
J. M. Kennedy, O.B.E.
H. Marryat.
F. W. Purse.
Col. A. P. Pyne.
E. Ridley.
P. J. Robinson, M.Eng.

And	*Representing*
A. C. Sparks	Association of Consulting Engineers.
A. Kirk	Association of Supervising Electrical Engineers.
E. B. Wedmore	British Electrical and Allied Industries Research Association.
F. Broadbent	British Electrical and Allied Manufacturers' Association.
Geoffrey F. Falk	
C. A. Martin	
C. Rodgers, O.B.E., B.Sc., B.Eng.	
J. B. Tucker	
A. J. L. Whittenham	
W. F. Bishop	Cable Makers' Association.
S. W. Melsom	
W. R. Rawlings	Electrical Contractors' Association.
E. A. Reynolds, M.A.	
R. A. Ure	Electrical Contractors' Association of Scotland.
J. Howard-Blood	Fire Offices Committee.
E. B. Hunter	
W. H. Tuckey	
H. W. Swann	Home Office.
R. W. L. Phillips	Incorporated Municipal Electrical Association.
J. W. J. Townley	
E. W. Farr	Independent Cable Makers' Association.

REPRESENTATIVES OF THE INSTITUTION ON OTHER BODIES

The following is a list of representatives of The Institution on other bodies, and gives the dates on which they were appointed:—

Bristol University:

H. F. Proctor (8 Jan., 1925).

British Cast Iron Research Association:

E. B. Wedmore (25 Sept., 1924).

British Electrical and Allied Industries Research Association:

Council:

J. M. Donaldson, M.C. (18 Dec., 1930).
C. P. Sparks, C.B.E. (18 Dec., 1930).

Sub-Committee on Connections to Large Gas-filled Lamps:

C. C. Paterson, O.B.E. (24 Oct., 1929).
B. Welbourn (24 Oct., 1929).

Sub-Committee on Earthing and Earth Plates:

S. W. Melsom (31 Jan., 1930).

British Electrical Development Association: Committee on Rural and Agricultural Electrification:

J. M. Donaldson, M.C. (20 Oct., 1927).
R. Grierson (20 Oct., 1927).

British Standards Institution:

Engineering Divisional Council:

P. V. Hunter, C.B.E. (11 April, 1935).
R. T. Smith (22 March, 1934).
W. B. Woodhouse (19 March, 1936).

Electrical Industry Committee:

Lt.-Col. K. Edgcumbe, T.D. (5 March, 1925).
F. Gill, O.B.E. (21 May, 1914).
J. S. Highfield (21 May, 1914).
E. H. Shaughnessy, O.B.E. (23 March, 1933).
R. T. Smith (21 May, 1914).

Technical Committee on Electric Clocks:

E. B. Hunter (5 Dec., 1935).

Technical Committee on Electric Power Cables:

S. W. Melsom (10 Jan., 1930).

Technical Committee on Electric Signs:

L. Barlow (14 May, 1931).
R. W. L. Phillips (17 Feb., 1932).

Technical Committee on Electrical Accessories:

H. J. Cash (31 March, 1925).
F. W. Purse (31 March, 1925).

Technical Committee on Electrical Instruments:

Lt.-Col. K. Edgcumbe, T.D. (15 Feb., 1923).

Technical Committee on Electrical Nomenclature and Symbols:

C. C. Paterson, O.B.E. (8 Jan., 1920).

Technical Committee on Electricity Meters:

A. J. Gibbons, B.Sc.Tech. (28 March, 1930).
O. Howarth (22 Oct., 1936).
G. F. Shotter (28 Feb., 1929).

Technical Committee on Identification of Pipe Lines in Buildings:

R. Grierson (11 May, 1933).

Technical Committee on Lifts, Hoists, and Escalators:

H. Marryat (25 Oct., 1934).

Technical Committee on Overhead Transmission Lines Material:

J. L. Eve (11 Nov., 1936).

Technical Committee on Regulations for Overhead Lines:

W. Fennell (23 April, 1936).
S. R. Siviour (23 April, 1936).

Technical Committee on Safety Requirements:

H. J. Cash (22 Oct., 1936).
R. W. L. Philips (22 Oct., 1936).
A. C. Sparks (22 Oct., 1936).

Technical Committee on Under-Floor Duct Systems:

E. B. Hunter (22 Oct., 1936).
H. W. Swann (22 Oct., 1936).

Technical Committee on Wireless Apparatus and Components:

E. H. Shaughnessy, O.B.E. (30 Sept., 1925).

Sub-Committee on Automatic Change-Over Switches for Emergency Lighting Systems:

E. Ridley (22 Oct., 1936).

British Standards Institution—*continued.*

Sub-Committee on Ceiling Roses:
H. J. Cash (23 Jan., 1924).
F. W. Purse (23 Jan., 1924).

Sub-Committee on Conduit Fittings:
H. J. Cash (18 May, 1927).

Sub-Committee on Connectors for Portable Appliances:
H. J. Cash (23 Jan., 1924).
F. W. Purse (23 Jan., 1924).
A. C. Sparks (16 May, 1935).

Sub-Committee on Connectors for Radio Apparatus:
R. W. L. Phillips (6 Jan., 1931).

Sub-Committee on Copper Conduit Tubes (Light Gauge):
H. Marryat (17 Dec., 1936).

Sub-Committee on Cut-outs for Radio Receivers:
S. W. Melsom (5 Dec., 1935).

Sub-Committee on Distribution Boards:
E. B. Hunter (25 Feb., 1927).
S. W. Melsom (25 Feb., 1927).

Sub-Committee on Instrument Transformers:
G. F. Shotter (22 Feb., 1934).

Sub-Committee on Lead Alloys for Cable Sheathing:
B. Welbourn (22 June, 1933).

Sub-Committee on Letter Symbols:
A. T. Dover (21 Nov., 1929).

Sub-Committee on Low-Voltage Cut-outs:
H. J. Cash (22 June, 1926).
E. B. Hunter (25 Feb., 1927).
S. W. Melsom (25 Feb., 1927).

Sub-Committee on Low-Voltage Transformers for Lighting Equipment and Bell-Ringing Circuits:
A. C. Sparks (22 Oct., 1936).

Sub-Committee on Mains Supply Apparatus for Radio Receivers, etc.:
R. W. L. Phillips (11 Dec., 1930).
F. W. Purse (16 Oct., 1928).

Sub-Committee on Non-Ignitable and Self-Extinguishing Boards for Electrical Purposes:
S. W. Melsom (24 Oct., 1935).
E. Ridley (24 Oct., 1935).

Sub-Committee on Protected-type Plugs and Sockets:
H. J. Cash (26 Oct., 1932).
F. W. Purse (26 Oct., 1932).
A. C. Sparks (16 May, 1935).

Sub-Committee on Radio Interference from Trolley-Buses and Tramcars:
C. C. Paterson, O.B.E. (7 Nov., 1935).

Sub-Committee on Radio Nomenclature and Symbols:
Col. A. S. Angwin, D.S.O., M.C., B.Sc.(Eng.) (7 April, 1932).

Sub-Committee on Telephone and Radio Connectors:
R. W. L. Phillips (28 Feb., 1935).
A. J. L. Whittenham (28 Feb., 1935).

British Standards Institution—*continued.*

Sub-Committee on Tumbler Switches:
H. J. Cash (23 Jan., 1924).
F. W. Purse (23 Jan., 1924).

Sub-Committee on Wall-plugs and Sockets:
H. J. Cash (23 Jan., 1924).
F. W. Purse (23 Jan., 1924).
A. C. Sparks (16 May, 1935).

Sub-Committee on Welding Plant and Equipment:
Major J. Caldwell, J.P. (26 Oct., 1933).

Panel on Graphical Symbols for Interior Installations:
J. R. Cowie (13 Nov., 1924).

Colliery Requisites Industry Committee:
C. T. Allan (3 July, 1924).

Technical Committee on Mining Electrical Plant.
A. C. Sparks (27 March, 1930).

Birmingham Regional Committee:
F. C. Hall.

Glasgow Regional Committee:
F. Anslow.

Manchester Regional Committee:
W. T. Anderson.

Newcastle Regional Committee:
S. A. Simon, B.A.

Sheffield Regional Committee:
M. Wadeson.

Technical Committee on Coal:
W. M. Selvey (19 Jan., 1928).

Technical Committee on Engine Testing Fittings:
W. M. Selvey (22 Oct., 1931).

Technical Committee on Engineering Symbols and Abbreviations:
A. T. Dover (21 Nov., 1929).

Technical Committee on Fans:
R. O. Kapp, B.Sc. (22 Oct., 1931).

Technical Committee on Land Boilers:
W. E. Highfield (2 July, 1931).
W. M. Selvey (7 April, 1932).

Technical Committee on Larch Poles:
B. Welbourn (21 Jan., 1932).

Technical Committee on Lightning Conductors:
Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng. (30 Jan., 1936).

Technical Committee on Methods of Test for Dust Extraction Plant:
C. L. Blackburn, B.A. (25 Oct., 1934).

Technical Committee on Pipe Flanges:
W. M. Selvey (14 April, 1921).

Technical Committee on Pump Tests:
R. S. Allen (2 July, 1931).

British Standards Institution—*continued.*

Technical Committee on Railway Signalling Apparatus:
A. F. Bound (24 Oct., 1929).

Technical Committee on Rating of Rivers:
G. K. Paton (20 Oct., 1927).

Technical Committee on Rubber Belting:
C. Rodgers, O.B.E., B.Sc., B.Eng. (5 Jan., 1928).

Technical Committee on Traction Poles:
T. L. Horn (4 Feb., 1926).

Sub-Committee on Accessories for Land Boilers:
W. M. Selvey (7 April, 1932).

Sub-Committee on Boiler and Superheater Tubes:
W. M. Selvey (7 April, 1932).

Sub-Committee on Fittings for Land Boilers:
W. M. Selvey (7 April, 1932).

Sub-Committee on Water-Tube Boilers:
W. E. Highfield (2 July, 1931).
W. M. Selvey (7 April, 1932).

Sub-Committee on Portable Railway Track:
R. T. Smith (25 Oct., 1928).

Illumination Industry Committee:
Lt.-Col. K. Edgcumbe, T.D. (28 Feb., 1924).
P. Good (28 Feb., 1924).
H. W. Gregory (26 Oct., 1933).
Prof. J. T. MacGregor-Morris (28 Feb., 1924).
J. W. J. Townley (16 May, 1935).

Building Industry, National Council for: Advisory Committee on Building Acts and Bye-laws:
F. W. Purse (20 Oct., 1932).
H. T. Young (20 Oct., 1932).

City and Guilds of London Institute:

Advisory Committee on Electrical Engineering Practice:
Prof. E. W. Marchant, D.Sc. (22 June, 1933).

Advisory Committee on Electrical Installation Work:
Prof. S. Parker Smith, D.Sc. (20 Oct., 1927).

Advisory Committee on Telecommunications:
E. H. Shaughnessy, O.B.E. (22 Oct., 1931).

Fellowship Committee:
W. H. Eccles, D.Sc., F.R.S. (19 April, 1928).

Council for the Preservation of Rural England:
J. M. Kennedy (10 Jan., 1929).

Electrical Association for Women:

Council:
A. P. M. Fleming, C.B.E., M.Sc. (18 Dec., 1924).

Committee for Training of Women Demonstrators:
E. E. Sharp (5 Nov., 1931).

Engineering Joint Council:
P. V. Hunter, C.B.E. (8 March, 1934).
J. M. Kennedy, O.B.E. (20 Feb., 1936).

Imperial College of Science and Technology: Governing Body:
W. M. Mordey (12 April, 1923).

Imperial Minerals Resources Bureau Conference: Copper Committee:
B. Welbourn (18 Sept., 1919).

Institute of Industrial Administration: Examinations Advisory Council:
A. P. M. Fleming, C.B.E., M.Sc. (25 Oct., 1934).

Institute of Metals: Corrosion Research Committee:
W. M. Selvey (19 July, 1923).

Institution of Civil Engineers:

Engine and Boiler Testing Committee:
C. P. Sparks, C.B.E. (19 Oct., 1922).

Earthing to Water Mains Sub-Committee:
Ll. B. Atkinson (20 Feb., 1936).
Dr. P. Dunsheath, O.B.E., M.A. (20 Feb., 1936).
F. W. Purse (20 Feb., 1936).
P. J. Ridd (20 Feb., 1936).

International Association for Testing Materials:
J. M. Kennedy, O.B.E. (5 July, 1928).

International Illumination Commission: British National Committee:
Lt.-Col. K. Edgcumbe, T.D. (27 Nov., 1913).
P. Good (18 Sept., 1919).
H. W. Gregory (26 Oct., 1933).
Prof. J. T. MacGregor-Morris (27 Nov., 1913).
J. W. J. Townley (16 May, 1935).

Joint Fuel Committee:
C. P. Sparks, C.B.E. (7 Jan., 1932).

Leeds Municipal Technical Library Committee:
T. B. Johnson (9 March, 1932).

Loughborough Technical College: Advisory Committee:
Ll. B. Atkinson (11 April, 1929).

Metalliferous Mining (Cornwall) School: Governing Body:
L. A. Hards (1 Dec., 1927).

National Physical Laboratory: General Board:
J. M. Donaldson, M.C. (7 Nov., 1935).
C. C. Paterson, O.B.E. (3 Nov., 1932).

National Register of Electrical Installation Contractors:
H. J. Cash (12 March, 1931).
P. V. Hunter, C.B.E. (18 Feb., 1926).
W. R. Rawlings (18 Feb., 1926).
W. M. Selvey (18 Feb., 1926).

National Smoke Abatement Society:
H. C. Lamb (26 Oct., 1933).
C. D. Taite (26 Oct., 1933).

Professional Classes Aid Council:
P. F. Rowell (20 April, 1928).

Royal Engineer Board:
W. B. Woodhouse (19 March, 1925).

Royal Society:

National Committee on Physics:
Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng. (19 Nov., 1936).

Royal Society—*continued.*

National Committee for Scientific Radio:

Prof. C. L. Fortescue, O.B.E., M.A. (19 Nov., 1936).
E. H. Rayner, M.A., Sc.D. (9 Nov., 1933).

Science Museum, South Kensington: Advisory Council:

W. M. Mordey (10 April, 1930).

Town Planning Institute: Committee on Overhead Transmission Lines:

J. M. Kennedy (7 April, 1932).

Union of Lancashire and Cheshire Institutes (Panel for Engineering):

A. P. M. Fleming, C.B.E., M.Sc. (28 Feb., 1924).
Prof. Miles Walker, M.A., D.Sc., F.R.S. (28 Feb., 1924).

University College, Nottingham: Electrical Engineering Advisory Committee:

A. D. Phillips (23 Feb., 1933).

War Office Mechanization Board:

W. H. Eccles, D.Sc., F.R.S. (19 Jan., 1928).

Women's Engineering Society:

A. P. M. Fleming, C.B.E., M.Sc. (25 Sept., 1924).

World Power Conference (British National Committee):

R. T. Smith (1 May, 1930).

TRANSFERS

The following transfers were effected by the Council at their meeting held on the 3rd December, 1936:—

Student to Graduate

Bamford, Raymund Joseph.
Booth, Eric Stuart, B.Eng.
Braines, William Frederick.
Brownbridge, Gilbert Arthur.
Burnett, Norman Whitmore.
Draper, John.
Erith, Henry Applin, B.Sc.
Fielding, Edward Armitage, B.Sc.Tech.
Franks, Robert, B.Eng.
French, Ewart John.
Gamble, John Slater, B.Sc.
Goodwin, James.
Hague, Arthur.
Harden, James George L.
Harper, Maurice Ernest.
Hefford, John Nelson.
Hill, John Norman.
Isaacs, George Glynn, B.Sc.
James, Derek Nigel A., B.Eng.
Jones, Stanley, B.Sc.
Linnell, Charles Edward.
Lowe, William Augustus, B.Sc.Tech.
Marsden, Harry Duncan N., B.Sc.
Martin, Charles Adrian A.
Medlycott, Harold Stuart.
Miles, James William.
Morgan, Ancel.
Nicol, James Campbell B., B.Sc.(Eng.).
Ockerse, Eric.
Olsen, Peter Louis, B.Sc.(Eng.).
Pannell, John Walter, B.Sc.(Eng.).
Ray, Donald Haldane.
Robinson, David John.
Ryley, Robert Henry E.
Snell, Herbert.
Stoughton, Robert Knyvett C.
Tait, James Sharp.
Theron, Gabriel Christiaan.
Thomson, William Charles, B.Sc.(Eng.).
Todd, Julian Kelsall, B.A.
Uhl, Arthur Henry G.
Williams, Frederic Calland, M.Sc., D.Phil.
Willshaw, William Ernest, M.Sc.Tech.
Wilson, Alastair Graeme.
Wilson, Noel John.
York, Raymond Alfred, B.Sc.

ACCESSIONS TO THE REFERENCE LIBRARY

[Note.—The books cannot be purchased at The Institution; the names of the publishers and the prices are included only for the information of members. (*) denotes that the book is also in the Lending Library.]

Air Ministry: Meteorological Office. Geophysical memoirs, no. 68. Point discharge in the electric field of the earth. An analysis of continuous records obtained at Kew Observatory. By F. J. W. Whipple and F. J. Scrase. 4to. 20 pp. (London: H.M. Stationery Office, 1936.) 1*s.* 6*d.*

Allcut, E. A., *M.Sc.(Eng.).* Principles of industrial management. 8vo. xiv + 218 pp. [Toronto: Sir Isaac Pitman and Sons, (Canada), Ltd., 1932.] 10*s.* 6*d.*

Ardenne, M. von. Television reception. Construction and operation of a cathode ray tube receiver for the reception of ultra-short wave television broadcasting. Translated by O. S. Puckle. 8vo. xv + 121 pp. (London: Chapman and Hall, Ltd., 1936.) 10*s.* 6*d.* (*)

Berg, E. J., *D.Sc.* Heaviside's operational calculus as applied to engineering and physics. 2nd ed. xv + 258 pp. (New York, London: McGraw-Hill Publishing Co., Ltd., 1936.) 18*s.* (*)

Bergtold, F., *Dr.-Ing.* Röhrenbuch für Rundfunk- und Verstärkertechnik. (3e Aufl.) 8vo. 202 pp. (Berlin: Weidmansche Buchhandlung, 1936.) 3.60 *gold marks.*

Bragg, W. L., *M.A., Sc.D., F.R.S.* Electricity. 8vo. xi + 286 pp. (London: G. Bell and Sons, Ltd., 1936.) 8*s.* 6*d.* (*)

British Standards Institution. British standard specifications. nos. 52, 81, 171, 686, 697, 698. 8vo. (London: British Standards Institution, 28, Victoria Street, S.W.1, 1936.) 2*s.* 2*d.* each post free, *except where otherwise indicated.*

no. 52, for dimensions of bayonet lamp-caps, lampholders and lampholder-plugs for voltages not exceeding 250 volts (Rev., July, 1936.)
no. 81, for instrument transformers. (Rev., July, 1936.)
no. 171, for the electrical performance of transformers for power and lighting. (Rev., July, 1936. *Price 3s. 9d. post free.*)
no. 686, methods for the analysis of coal ash and coke ash. (July, 1936.)
no. 697, for rubber gloves for electrical purposes. (Aug., 1936.)
no. 698, for papers (unvarnished) for electrical purposes, excluding asbestos papers and those used in the manufacture of cables. (Sept., 1936.)

Chapman, S., *M.A., D.Sc., F.R.S.* The earth's magnetism. sm. 8vo. xi + 116 pp. (London: Methuen and Co., Ltd., 1936.) 3*s.* 6*d.* (*)

Comité Consultatif International Téléphonique (C.C.I.F.). Proceedings of the Xth plenary meeting, Budapest, 3rd–10th September, 1934. English edition. 4to. 659 pp. (London: The International Standard Electric Corporation, 1936.) 25*s.*

Croft, T. American electricians' handbook. A reference book for practical electrical workers. 4th ed., revised by C. C. Carr. sm. 8vo. viii + 1051 pp. (New York, London: McGraw-Hill Publishing Co., Ltd., 1936.) 24*s.*

Das, M. M. Experimental electricity. 8vo. 2 pts. xvi + 334; xv + 98 pp. (London: The English Universities Press Ltd., 1935–36.). pt. 1, 4*s.* 6*d.*; pt. 2, 3*s.* 6*d.*

Eddington, *Sir* A., *D.Sc., LL.D., F.R.S.* Relativity theory of protons and electrons. la. 8vo. vi + 336 pp. (Cambridge: University Press, 1936.) 21*s.*

Electricity Commission. Report on an electricity breakdown which occurred at Bradford in February, 1936, by H. Nimmo. la. 8vo. 23 pp. (London: H.M. Stationery Office, 1936.) 5*s.*

Eshbach, O. W. Handbook of engineering fundamentals. Prepared by a staff of specialists under the editorship of O. W. E. 8vo. *var. pagin.* (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1936.) 25*s.*

Filon, L. N. G., *C.B.E., D.Sc., F.R.S.* A manual of photo-elasticity for engineers. sm. 8vo. xi + 140 pp. (Cambridge: University Press, 1936.) 5*s.*

Gangadhariah, H. K., and Ferro, T. E. Electrical law and practice in India. 8vo. xiv + 685 pp. (Bombay: Gangadhariah and Ferro, 1935.) 30*s.*

Glasgow, R. S., *M.S.* Principles of radio engineering. 8vo. xii + 520 pp. (New York, London: McGraw-Hill Book Co., Inc., 1936.) 24*s.* (*)

Harwood, P. B. Control of electric motors. 8vo. vii + 390 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1936.) 22*s.* 6*d.* (*)

Hattingh, J. T., *D.Sc.* A universal stress sag chart for power line computations. 8vo. xii + 74 pp. (London: Blackie and Son, Ltd., 1936.) 12*s.* 6*d.*

Hauffe, G., *Dr.-Ing.* Ortskurven der Starkstromtechnik. Einführung in ihre Theorie und Anwendung. 8vo. x + 174 pp. (Berlin: Julius Springer, 1932.) *RM.* 15.50.

Hirst, A. W., *M.Sc. (Eng.).* Electricity and magnetism for engineering students. 8vo. xv + 388 pp. (London: Blackie and Sons, Ltd., 1936.) 15*s.* (*)

Hogben, L. Mathematics for the million. A popular self educator. 8vo. 647 pp. (London: George Allen and Unwin, Ltd., 1936.) 12*s.* 6*d.* (*)

Holstein-Rathlou, E. von. Über die Stromverhältnisse bei augenblicklich tödlichen elektrischen Unfällen. 8vo. 70 pp. (Kopenhagen: Aschehoug Dansk Vorlag, 1936.)

Ibbetson, W. S. Accumulator charging, maintenance and repair. 5th ed. sm. 8vo. xii + 151 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1936.) 3*s.* 6*d.* (*)

International Electrotechnical Commission. I.E.C. recommendations for standard direction of motion of operating devices and for indicating lamps for circuit-breakers. Publication 54. 4to. 11 pp. (London: I.E.C., 1936.) 2*s.*

—— Report of plenary meetings held June, 1935, Scheveningen-Brussels. 4to. 258 pp. (London: I.E.C., 1936.) 10*s.* 6*d.*

Kaye, G. W. C., *O.B.E., M.A., D.Sc.*, and Laby, T. H., *M.A., D.Sc., F.R.S.* Tables of physical and chemical constants and some mathematical functions. 8th ed. 8vo. 162 pp. (London: Longmans, Green and Co., 1936.) 14*s.*

Kearton, W. J., *D.Eng.* Steam turbine operation. A textbook on the installation, running, maintenance, and testing of steam turbines. 2nd ed. xii + 346 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1936.) 12*s.* 6*d.* (*)

Krönert, J., *Dr.* Messbrücken und Kompensatoren. Band 1, Theoretische Grundlagen. 8vo. 282 pp. (München, Berlin: R. Oldenbourg, 1935.) *RM.* 13.80.

Kunerth, W., *Ph.D.* A text-book of illumination. 2nd ed. 8vo. xii + 276 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1936.) 15*s.* (*)

Lange, B., *Dr.* Die Photoelemente und ihre Anwendung. 2 teil. 8vo. (Leipzig: J. A. Barth, 1936.)

teil 1, Entwicklung und physikalische Eigenschaften. vi + 132 pp. *RM.* 9.60
teil 2, Technische Anwendung. viii + 94 pp. *RM.* 6.75.

Lavanchy, C. Méthode générale de calcul des réseaux électriques maillés en régimes équilibrés et déséquilibrés. sm. 8vo. viii + 134 pp. (Paris: Dunod, 1936.) 43 *francs.*

Lewis, E. J. G. Television technical terms and definitions. sm. 8vo. v + 95 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1936.) 5*s.*

Lubberger, F., *Dr.-Ing.* Die Fernsprechanlagen mit Wahlerbetrieb. (Automatische Telephonie). 5e Aufl. 8vo. 347 pp. Diagrams 82 pp. (München, Berlin: R. Oldenbourg, 1935.) *RM.* 13.50.

McArthur, E. D. Electronics and electron tubes. 8vo. viii + 173 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1936.) 12*s.* 6*d.* (*)

McMullin, D., and Parkinson, A. C. An introduction to engineering mathematics. 8vo. viii + 266 pp. (Cambridge: University Press, 1936.) 4*s.*

Mauduit, A., and Lambœuf, C. La dynamo. Théorie et construction des machines électriques à courant continu. 8vo. vi + 462 pp. (Paris: J. B. Baillière et Fils, 1936.) 80 *francs.*

Meiners, G. Die Technik selbsttätiger Steuerungen und Anlagen. 8vo. 225 pp. (München, Berlin: R. Oldenbourg, 1936.) *RM.* 12.50.

Ministry of Transport. Report of the Committee on Electricity Distribution, May, 1936. 8vo. 103 pp. 6 graphs. (London: H.M. Stationery Office, 1936.) 2*s.*

Moyer, J. A., and Wostrel, J. F. Radio receiving and television tubes. Including applications for distant control of industrial processes and precision measurements. (New York, London: McGraw-Hill Book Co., Inc., 1936.) 24*s.* (*)

Myers, L. M. Television optics: an introduction. 8vo. x + 338 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1936.) 30*s.* (*)

National Electrical Manufacturers Association. nema rubber insulated building wire and cable standards. [1], Performance grade compound. Publication no. 36-33, April, 1936. 4to. 16 pp. [2], 30 per cent grade compound. Publication no. 36–32, April, 1936. 4to. 19 pp. (New York: N.E.M.A., 1936.) 25 *cents each.*

Orr, J., and Forrest, A. W. An introduction to neon lighting. sm. 8vo. 80 pp. (London: Blackie and Sons, Ltd., 1936.) 3*s.*

Palmer, L. S., *D.Sc., Ph.D.* Wireless engineering. 8vo. xii + 544 pp. (London: Longmans, Green and Co., 1936.) 21*s.* (*)

Picou, R. V. Les aimants: calcul et applications. 2e éd. 8vo. vi + 123 pp. (Paris: Dunod, 1936.) 22 *francs.*

Rapson, E. T. A. Problems in radio engineering. 2nd ed. sm. 8vo. viii + 103 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1935.) 3*s.* 6*d.* (*)

REYNER, J. H. Modern radio communication. A manual of modern theory and practice, covering the syllabuses of the City and Guilds examinations and suitable for candidates for the P.M.G. Certificate. With a foreword by G. W. O. Howe. 2 vol. (vol. 1, 6th ed., xiii + 330 pp.; vol. 2, 2nd ed., xi + 220 pp.) sm. 8vo. (London: Sir Isaac Pitman and Sons, Ltd., 1936.) vol. 1, 5*s.*, vol. 2, 7*s.* 6*d.* (*)

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SCHNEIDER, O. Einflüsse der Sonne auf die lunare Variation der Erdmagnetismus. (Veröffentlichungen des Meteorologischen Instituts der Univ. Berlin, Bd. 1, Heft 3). 8vo. 43 pp. (Berlin: Dietrich Reimer, 1936.) *RM.* 2.75.

SMITH, S. P., *D.Sc.* Electrical engineering laboratory manual: measurements. sm. 8vo. xii + 235 pp. (London: Oxford University Press, 1936.) 5*s.* (*)

SOWERBY, A. L. M., *M.Sc.* Foundations of wireless. 8vo. xii + 260 pp. (London: Iliffe and Sons, Ltd., 1936.) 4*s.* 6*d.* (*)

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TELEVISION COMMITTEE. Report of the Television Committee. Presented by the Postmaster-General to Parliament . . . January, 1935. 8vo. 27 pp. (London: H.M. Stationery Office, 1935.) 6*d.*

WALTER, J. La signalisation des chemins de fer. tome 1, Conditions générales de la sécurité—Dispositifs de signalisation. 8vo. 184 pp. (Paris: Léon Eyrolles, 1936.)

WORLD POWER CONFERENCE. Statistical Year-book of the W.P.C., no. 1, 1933 and 1934. Edited by F. Brown. 4to. 111 pp. (London: World Power Conference, 36 Kingsway, W.C.2., 1936.) 20*s.*

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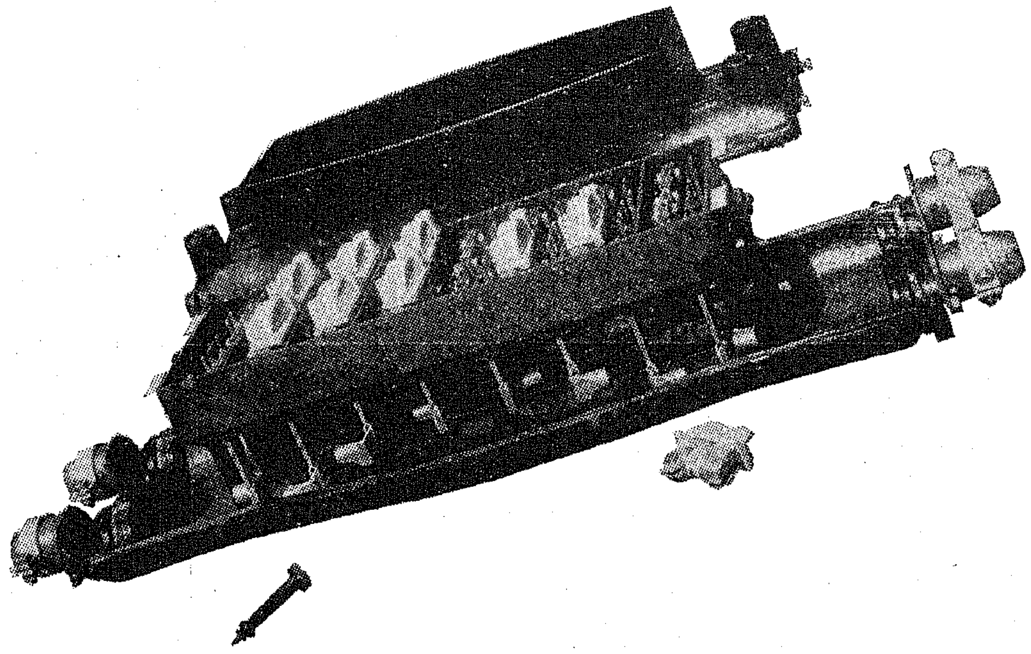

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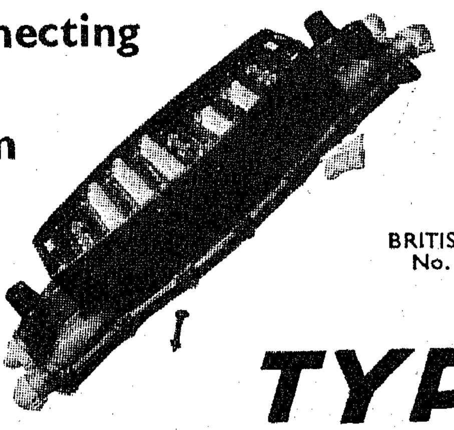

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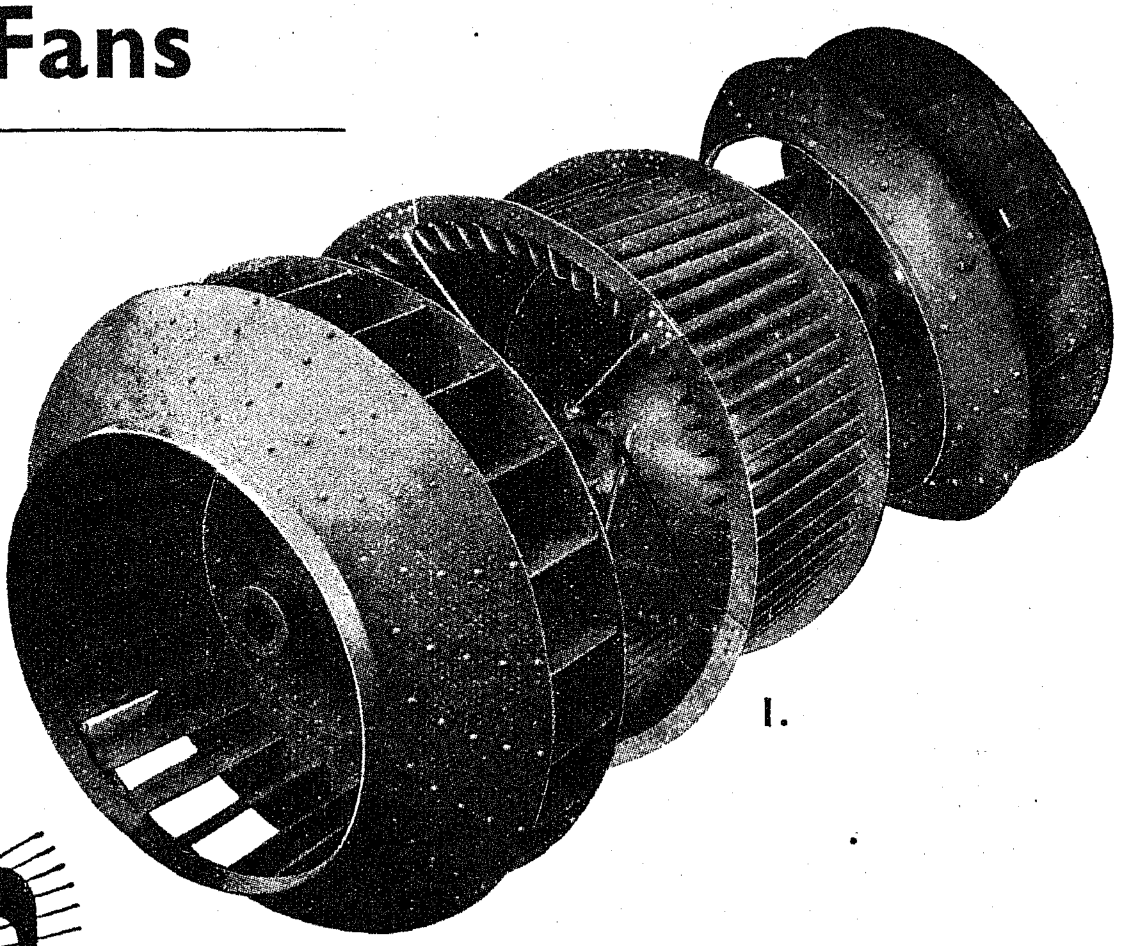

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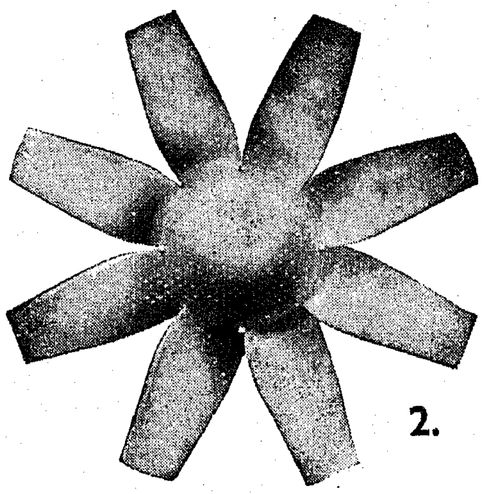

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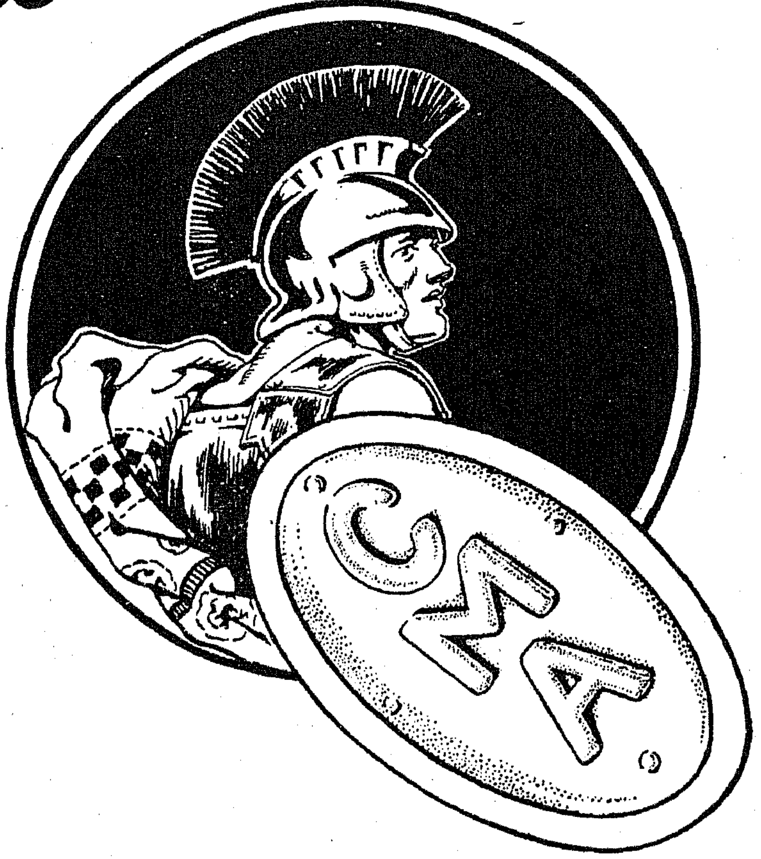

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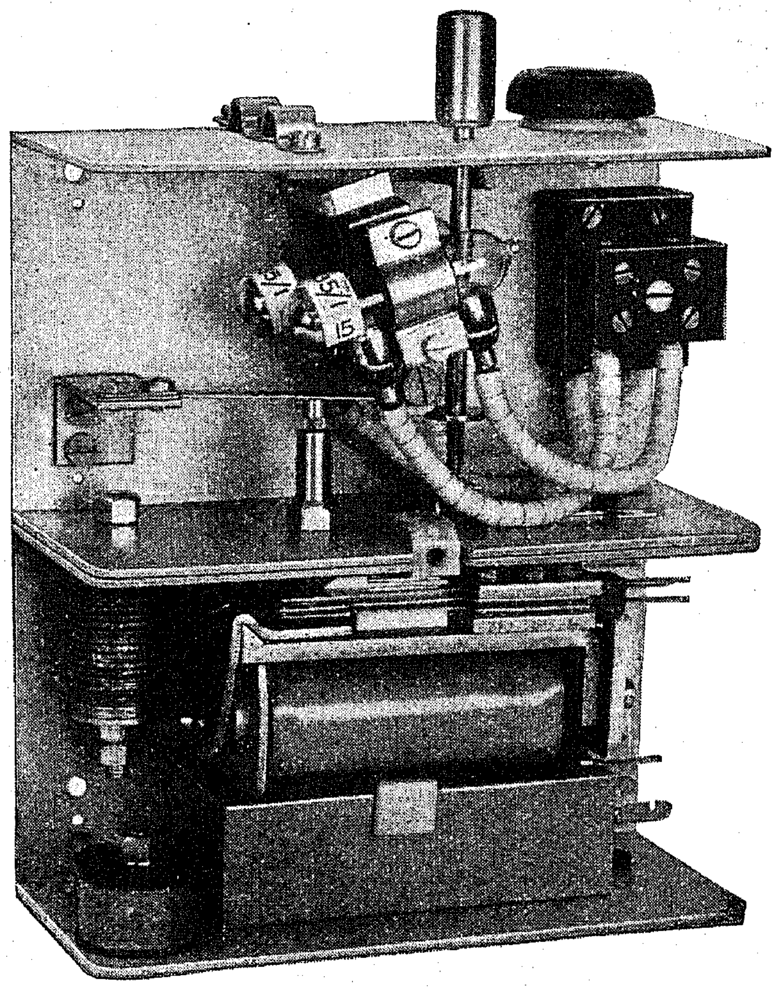

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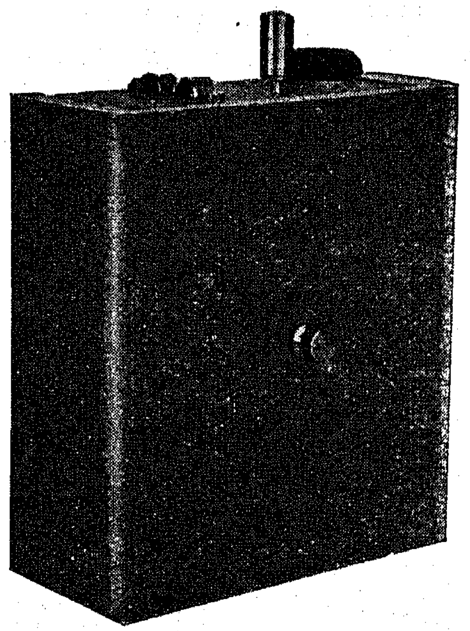

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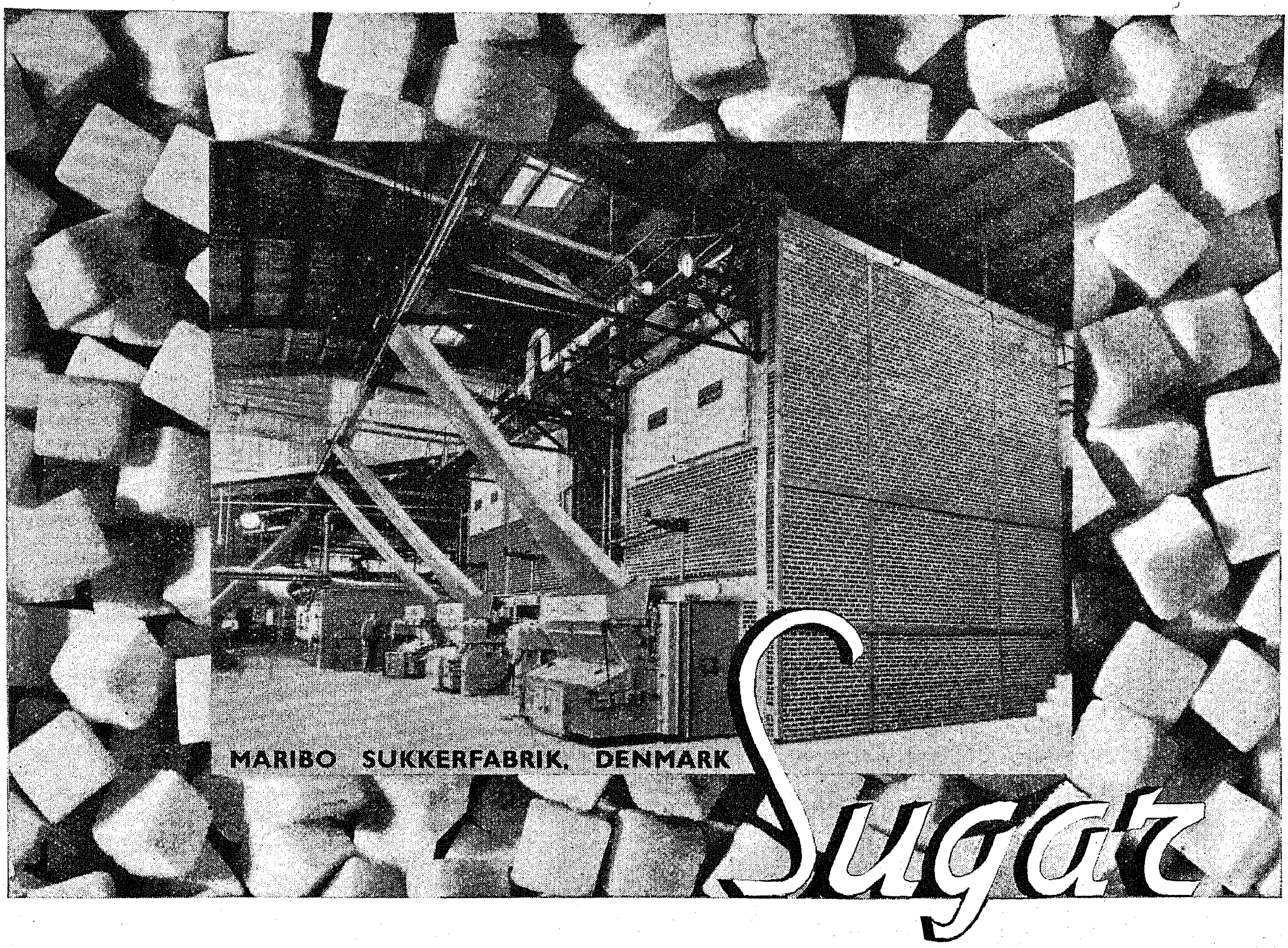

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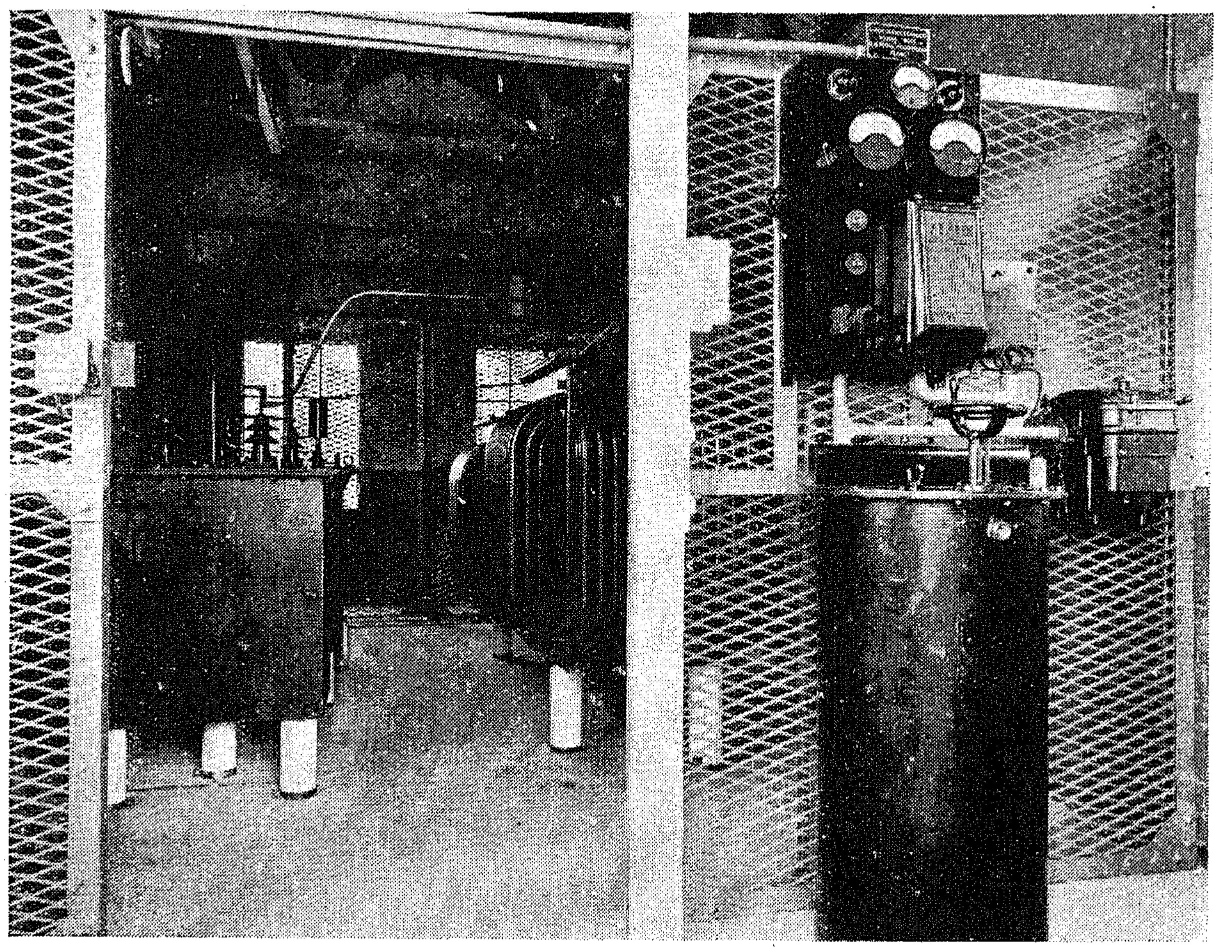

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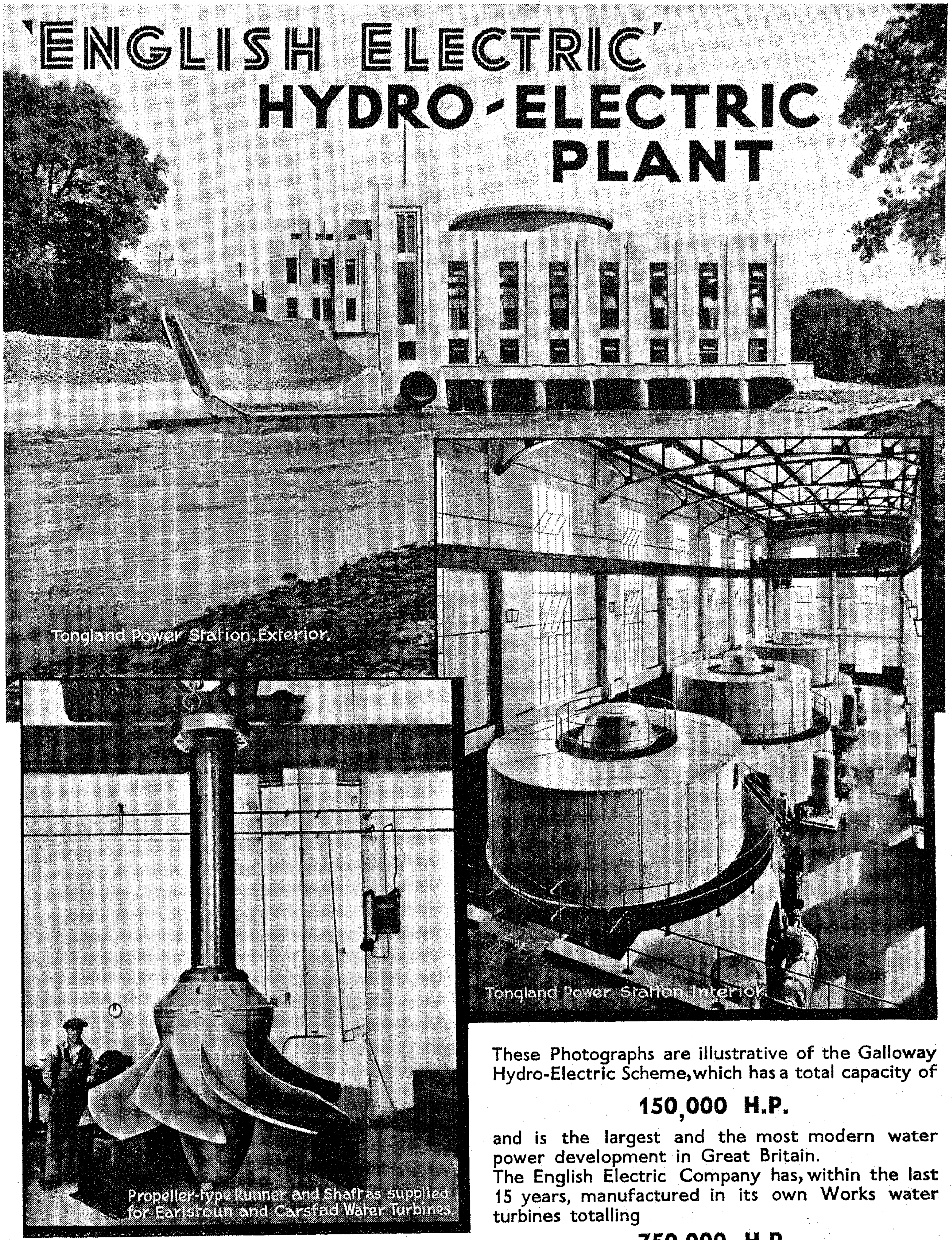

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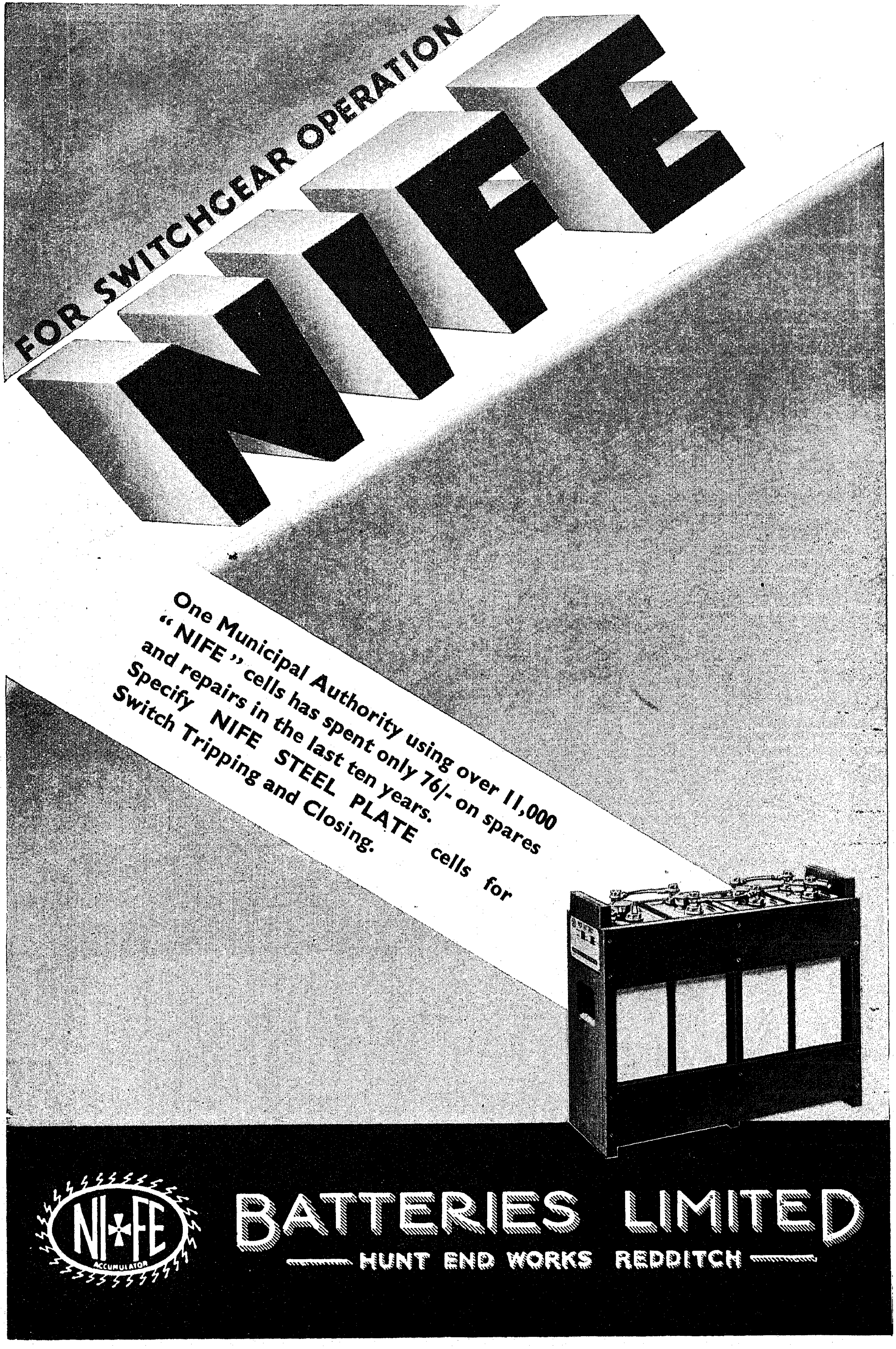

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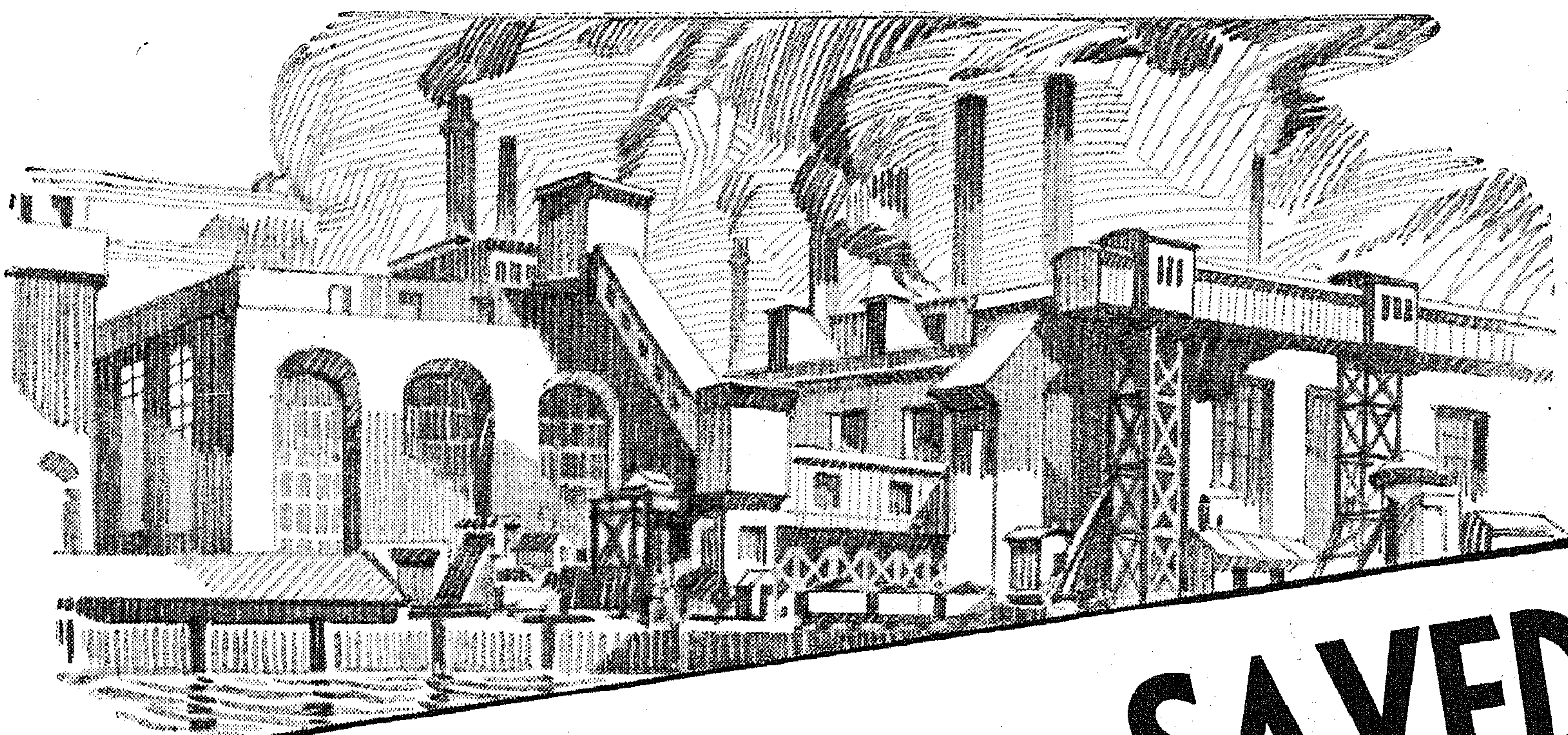

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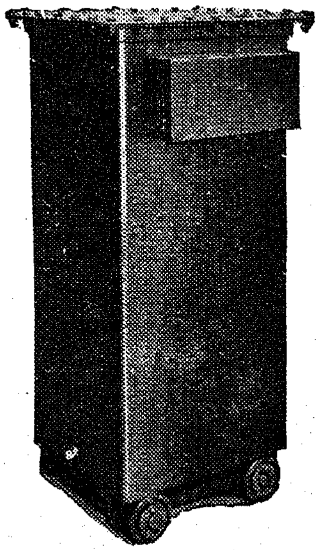

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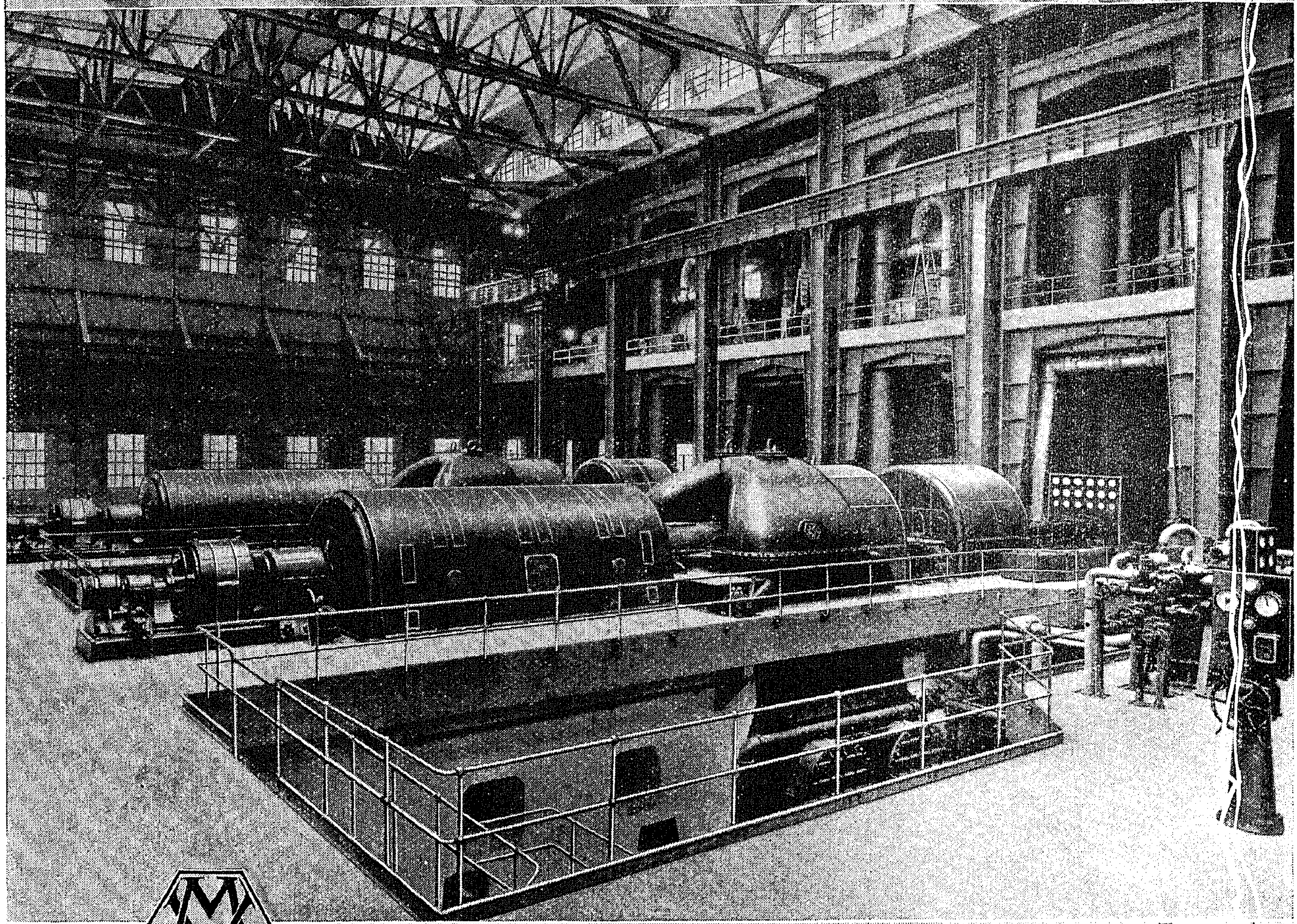

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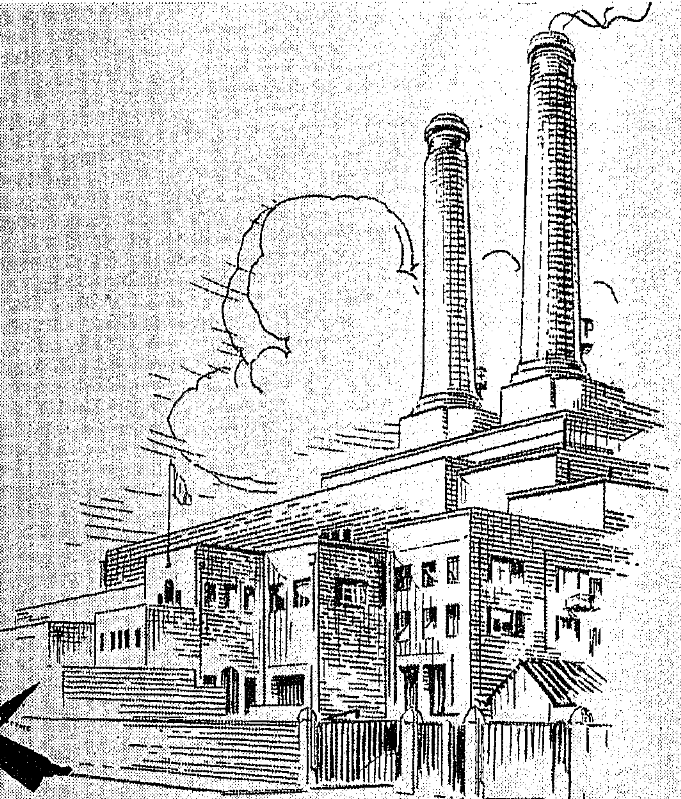

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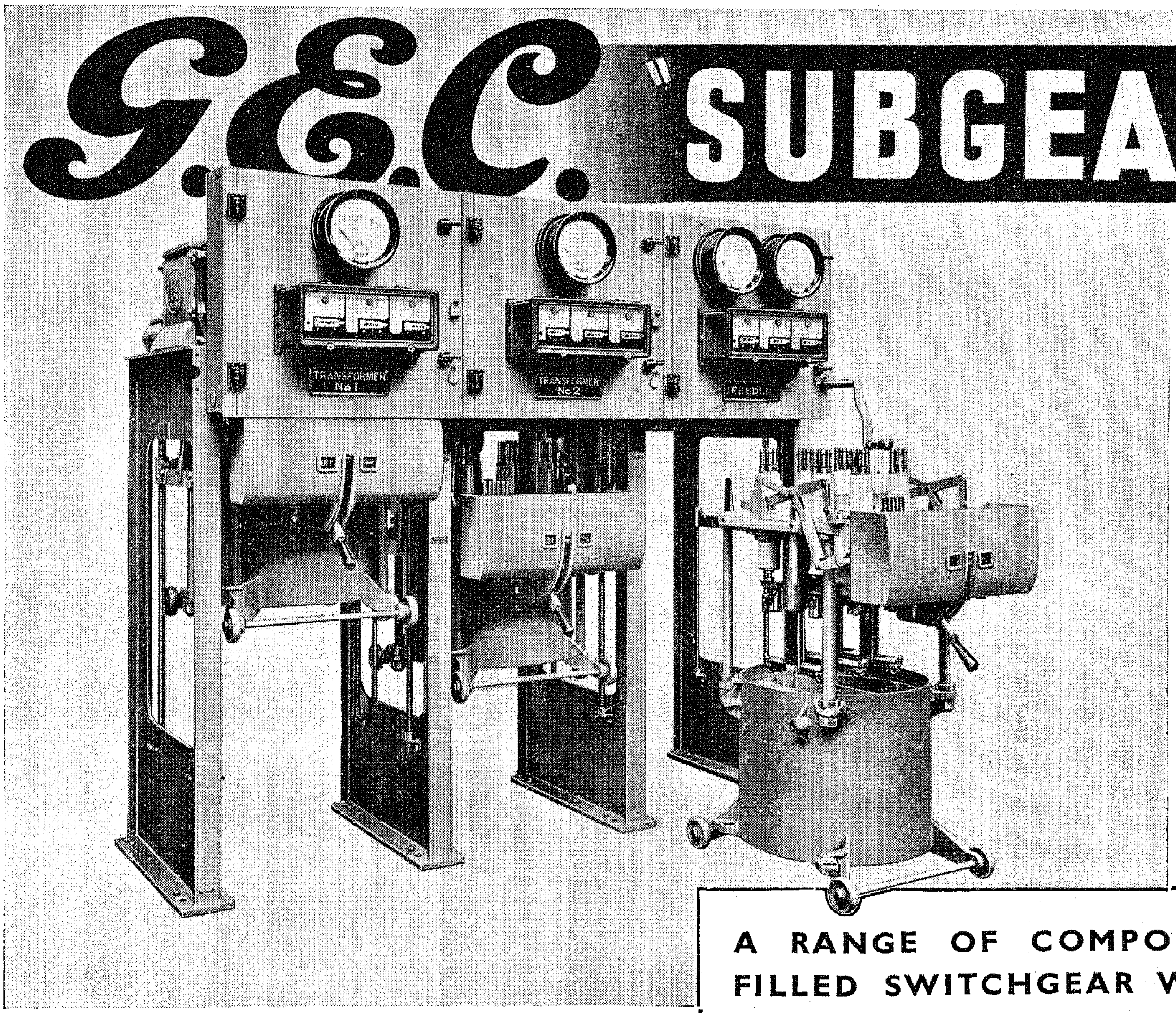

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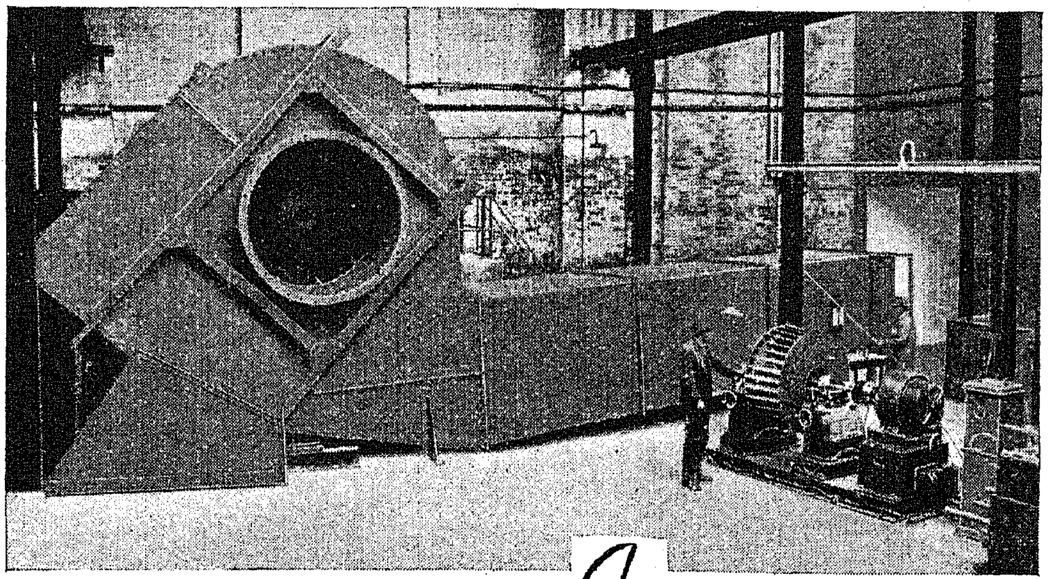

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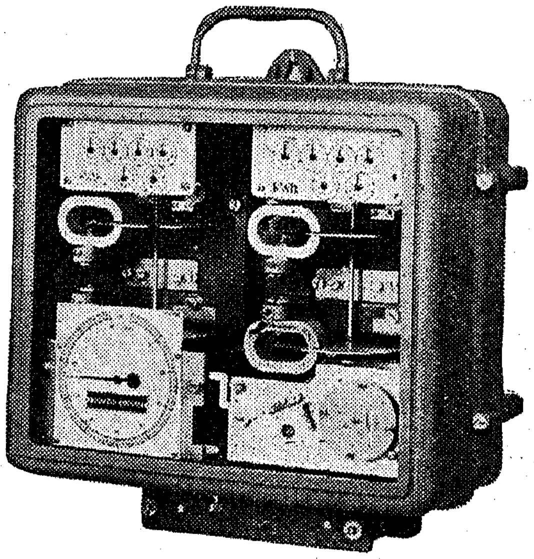

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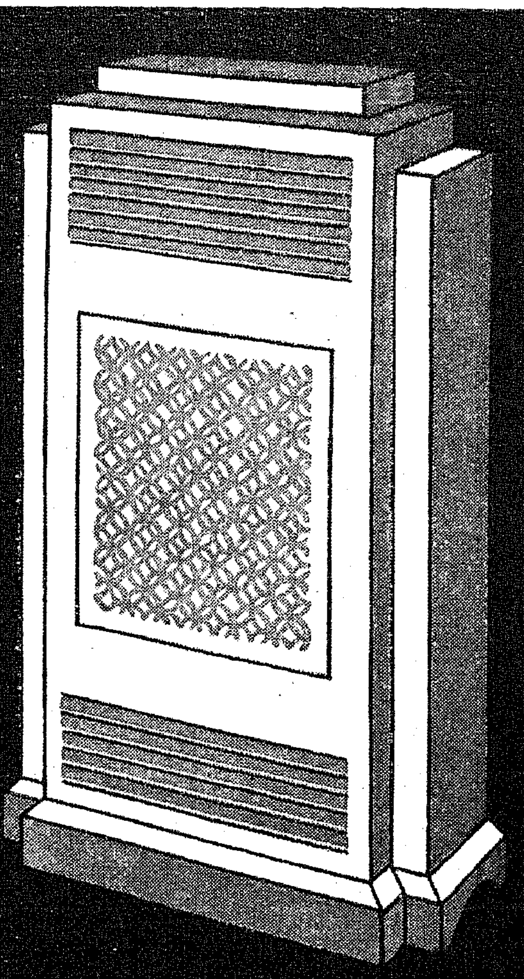

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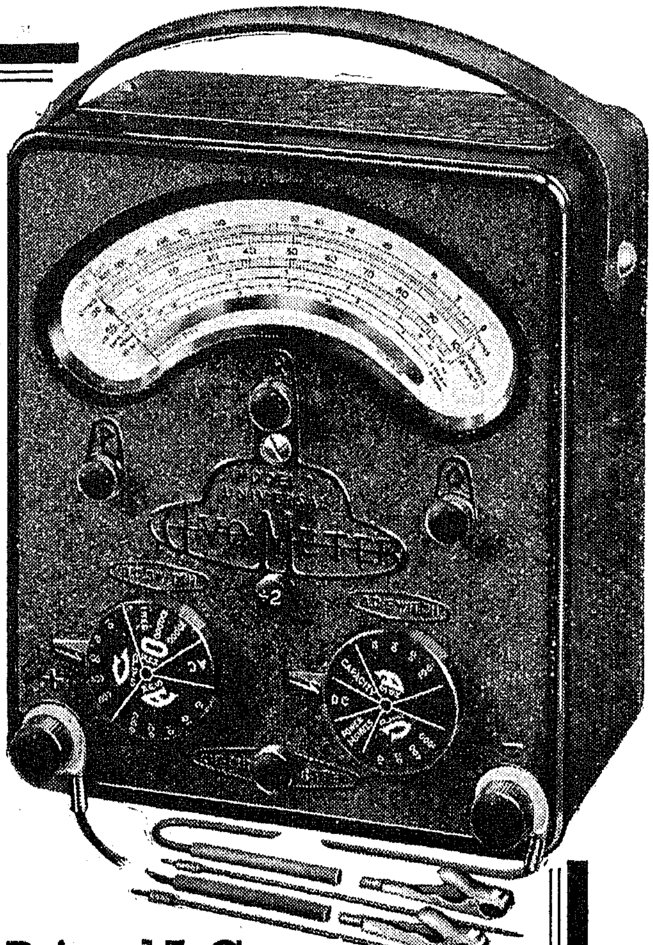

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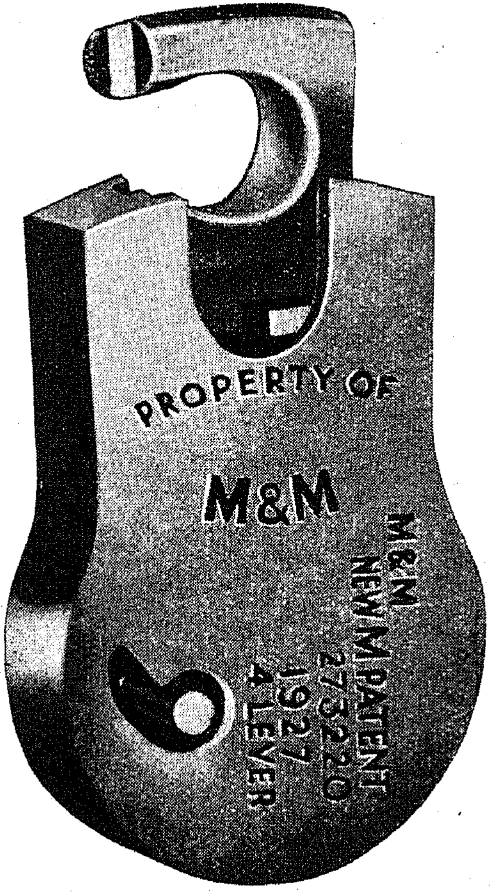

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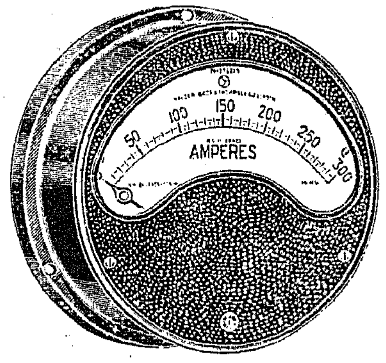

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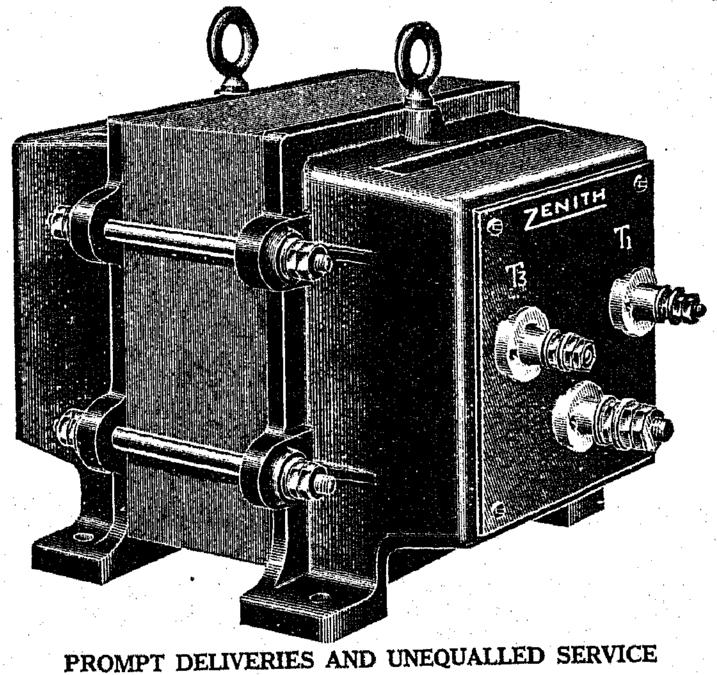

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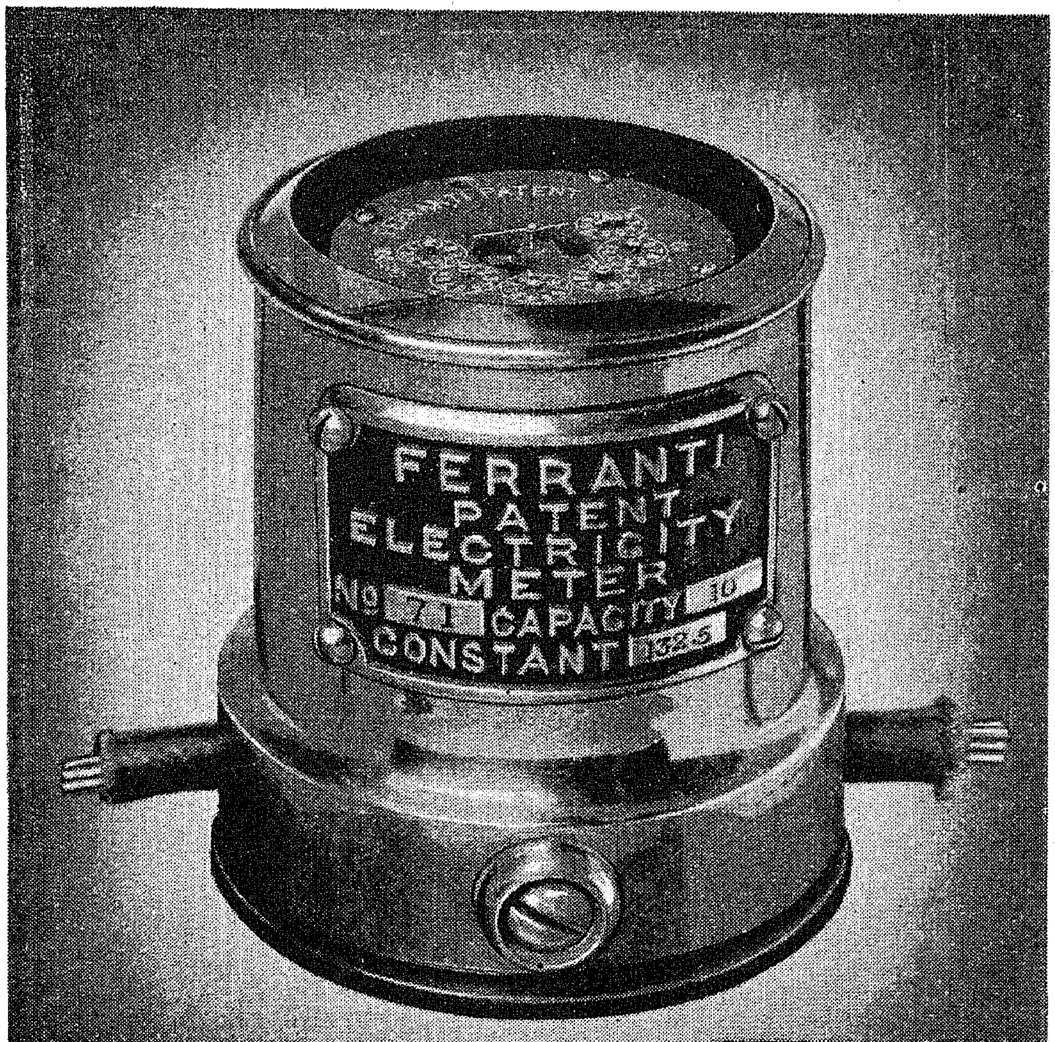

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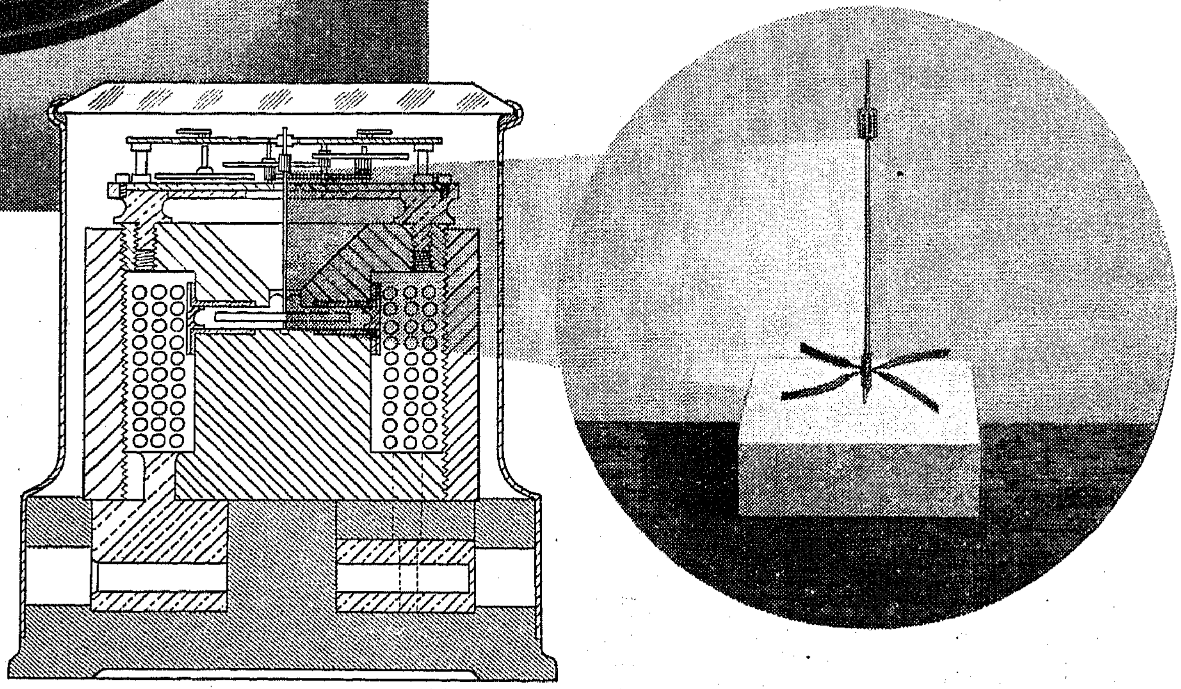

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